TEST EDITION
THE TEXTBOOK OF
PHYSICS
For Grade 9
Sindh Textbook Board, Jamshoro

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PREFACE

The century we have stepped in, is the century of Physics. The modern disciplines Physics are strongly influencing not only all the branches of science but each and every aspect human life.

To keep the students. abreast with the recent knowledge, it is a must that the curricula, at all the levels, be updated regularly by introducing the rapid and multidirectional development taking place in all the branches of Physics.

The recent book of Physics for class IX has been written in this preview and in accordance with the revised curriculum prepared by Ministry of Education, Govt of Pakistan, Islamabad reviewed by independent team of Bureau of Curriculum, Jamshoro sindh. Keeping in view of the importance of Physics, the topics have been revised and re-written according to the need of the time.

Since long Physics was teaching only in X class, the text book was consits of 18 units which was unable to complete in working hours. It has been decided now the Physics syllabus will be divided into portions, one should teach in 9th class and other will teach 10th class. So this book is consist of 9 units which have been thoroughly revised and re-written to meet the requirement of the curriculum.

Among the new editions are the introductory paragraphs, information boxes, summaries and a variety of extensive exercises which i think will not only develop the interest but also add a lot to the ut

ility of the book.

The Sind Textbook Board has taken great pains and incurred expenditure in publishing this book inspite to its limitations. A textbook is indeed not the last word and there is always room for improvement. While the authors have tried their level best to make the most suitable presentation, both in terms of concept and treatment, there may still have some deficiencies and omissions. Learned teachers and worthy students are, therefore, requested to be kind enough to point out the short comings of the text or diagrams and to communicate their suggestions and objections for the improvement of the next edition of this book.

In the end, I am thankful to our learned authors, editors and specialist of Board for their relentless service rendered for the cause of education.

Chairman
Sindh Textbook Board

Unit - 1

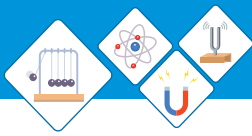
Physical Quantities And Measurement

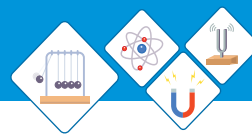
Nature is described as a pragmatic set of rules followed by all the things around us. It is something which is much greater than the imagination of humans. It is observable, it is surprising but it is somehow explainable, its architecture has been designed with very beautiful patterns, strict rules but with simplicity. A science which explores the nature is Physics.

Students Learning Outcomes (SLOs)

After learning this unit students should be able to:

- Describe the crucial role of Physics in Science, Technology and Society
- List with brief description of various branches of physics
- Choose a proper instrument (meter rule, Vernier calipers, screw gauge, physical balance stop watch, measuring cylinder) for the measurement of length, diameter, mass, time and volume in daily life activities.
- Interconvert the prefixes and their symbols to indicate multiple and sub-multiple for both base and derived units
- Write the answer in scientific notation in measurements and calculations
- Define term density with S.I unit
- Determine density of solids and liquids
- Describe the need of using significant figures for recording and stating results in laboratory.

Why do we study physics? Which device will you choose to measure the length of a small cylinder? How will you determine the thickness of a piece of wire? How will you find the volume of small stone? why ice floats while a coin sinks in the water? After learning this unit you will be answer these and other similar questions.

Quote

"No one undertakes research in physics with the intention of winning a prize. It is the joy of discovering something no one knew before."
Stephen Hawking

1.1 INTRODUCTION TO PHYSICS

One of the most basic and ancient science is the Physics. The word science refers to the study of a fact by collecting information through observation, presenting it in a mathematical way, justifying the idea with experiment and finally making a conclusion about the fact. Thus physics can be defined as:

Physics is the branch of science which observes the nature represents it mathematically and conclude with the experiment.

Do You Know!

Physics Derived from Ancient Greek 'physicos' meaning 'knowledge of nature'.

It basically deals with the behavior and structure of matter and the energy that derives the matter. Physics is the branch of natural science that studies matter, its motion, its behavior through space and time and the related entities of energy and force. Physics is one of the most fundamental scientific disciplines, and its main goal is to understand how the universe behaves.

It is a matter of fact that Physics can be considered as the mother of all sciences. The beauty of physics lies in its Laws that govern this whole universe from an atom to large scale galaxies and in its experiments from home to large scale experiment labs. Physicist are categorized into two categories: those who observe the nature solve its mysteries with available

and missing information, present their theories with mathematical approach. They are known as theoretical physicist and other are more interested to test those theories with experiments are known as experimental physicists.

Since from the beginning of the universe, the structure of universe is very straight forward, the classification of physics was not that much easy but as the physicist explained the universe, they classified Physics into many branches. These branches show the spectrum and scope of Physics around us and help scientist to describe ideas in a well-organized way.

The main branches of Physics are as follows.

Fig. 1.1Mechanics

Fig 1.2 Thermodynamics

Fig 1.3Electricity

Fig 1.4 Magnetism

Mechanics

This branch of physics is mainly concerned with the laws of motion and gravitation.

Thermodynamics

Thermodynamics deals with heat and temperature and their relation to energy and work.

Electricity

Electricity is the study of properties of charges in rest and motion

Magnetism

Magnetism is the study of magnetic properties of materials

Atomic Physics

Atomic physics deals with the composition structure and properties of the atom

Fig. 1.5 Atomic Physics

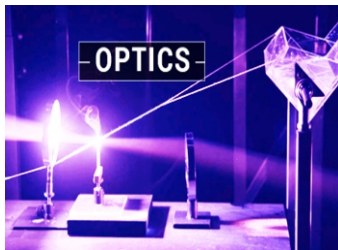



Fig. 1.6 Optics

Fig. 1.7 Sound

Fig. 1.8 Nuclear Physics

Optics

Optics studies physical aspects of light and its properties with the help of optical instruments.

Sound

Sound is the study of production, properties and applications of sound waves.

Nuclear physics

Nuclear physics deals with the constituents, structure, behavior and interactions of atomic nuclei.

Particle physics

Particle Physics studies the elementary constituents of matter and radiation, and the interactions between them.

Astrophysics

The study of celestial objects with the help of laws of physics is known as **Astrophysics**.

Plasma physics

The study of ionized state of mater and its properties is known as **Plasma Physics**.

Geo physics

The study of internal structure of earth is known as **Geo physics**.

Importance of Physics in Science Technology and Society

Society's reliance on technology represents the importance of physics in daily life. Many aspects of modern society would not have been possible without

the important scientific discoveries made in the past. These discoveries became the foundation on which current technologies were developed.

Discoveries such as magnetism, electricity, conductors and others made modern conveniences, such as television, computers, smart phones, medical instruments, other business and home technologies possible. Moreover, modern means of transportation, such as aircraft and telecommunications, have drawn people across the world closer together all rely on concepts of physics.

Fig. 1.9 Particle Physics

Fig. 1.10 Astro Physics

1.2 MEASURING INSTRUMENTS

Physics is much concerned with matter and energy and the interaction between them which is explained with the help of describing the mathematical relations between various physical quantities. All **physical quantities** are important for describing the nature around us. A physical quantity is a physical property of a phenomenon, body, or substance that can be quantified by measurement.

A physical quantity can be expressed as the combination of a magnitude expressed by a number – usually a real number – and a unit. Physical quantities are classified into two categories:

- Fundamental quantities
- Derived physical quantities.

Fig. 1.11 Plasma Physics

Physical quantities which cannot be explained by other physical quantities are called fundamental physical quantities.

There are seven fundamental physical quantities and are listed in table 1.1 along with their units.

Fig. 1.12 Geo Physics

Table 1.1 Fundamental quantities and their S.I units

Fundamental quantities	S.I Unit	Symbol of Unit
Length	meter	m
Mass	Kilogram	kg
Time	second	s
Electric current	Ampere	A
Temperature	Kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

Physical quantities which are explained on the basis of fundamental physical quantities are called derived physical quantities.

Table1.2 derived quantities and their units

Derived Quantities	S.I Unit	Symbol of Unit
Volume	cubic meter	m^3
Velocity	meter per second	$m^{-1}s$
Force	Newton	N
Density	kilogram per cubic meter	kg/m^3
Acceleration	meter per second square	m/s^2

All physical quantities are either calculated mathematically or measured through an instrument. Scientist, Engineers, Doctors and others like blacksmith, carpenter, and goldsmith even the workers and ordinary human's measure those physical quantities with the help of instruments. For instance, your doctor uses a thermometer to tell your body temperature, a carpenter uses the inch tape to measure the length of woods required for furniture.

Do You Know!

Some Physical quantities are unit-less. Such as Elastic modulus, Plane angle and solid angle

Do You Know!

The notion of physical dimension of a physical quantity was introduced by Joseph Fourier in 1822 by convention, physical quantities are organized in a dimensional system built upon base quantities, each of which is regarded as having its own dimension.

A puncture mender uses air gauges to check the air pressure in the tyre. Similarly, a chemical engineer uses hydrometer for describing the density of a liquid.

Measuring the physical quantity correctly with instrument is not an easy task for scientist and engineers. Scientist are seriously concerned with the accuracy of the instrument and its synchronization. Moreover, the instrument they design mostly for their own sake of research which readably goes on to commercial market. Many of the instruments we use today are inventions of pioneers of science. Usually, the basic physical quantities that we use in our daily life are measured with basic and simple instruments.

Do You Know!

Use of every instrument is restricted by smallest measurement that it can perform which is called least count.

The Standard of Length

If there is any measurement that has proven to be the most useful to humanity, it is length. For examples units of length include the inch, foot, yard, mile, meter etc.

The length is defined as the minimum distance between two points lying on same plane.

The **meter** (m) is the SI unit of **length** and is defined as:

The length of the path traveled by light in vacuum during the time interval of 1/299 792 458 of a second.

The basic measurement of length can be obtained with the help of a meter rod or an inch tape.

Do You Know!

1000m = 1km
100cm =1m
1cm = 10mm
1inch = 2.53cm
12 inch = 1 ft
1 yard = 3ft

Meter Rule

A **meter rule** is a device which is used to measure length of different objects. A meter rule of length 1m is equal to 100 centimeters (cm). On meter rule each cm is divided further in to 10 divisions which

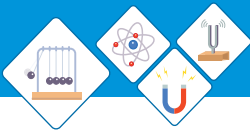



Fig 1.13 Meter Rule

Fig 1.14 Vernier Calipers

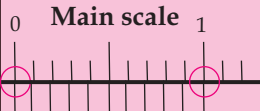
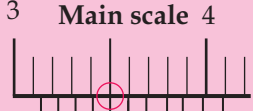
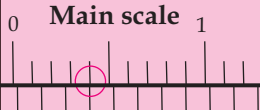
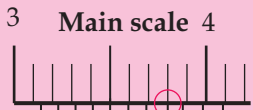
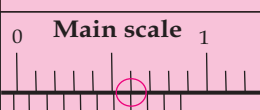
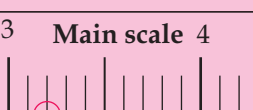
Fig 1.15 Digital vernier calipers

are called millimeters (mm). So, a meter rule can measure up to 1mm as smallest reading. It is made up of a long rigid piece of wood or steel(Fig 1.13).

The zero-end of the meter rule is first aligned with one end of the object and the reading is taken where the other end of the object meets the meter rule.

Vernier Caliper

The **Vernier Caliper** is a precision instrument that can be used to measure internal and external distance extremely accurate. It has both an imperial and metric scale. A Vernier caliper has main jaws that are used for measuring external diameter, as well as smaller jaws that are used for measuring the internal diameter of objects. Some models also have a depth gauge. The main scale is fixed in place, while the Vernier scale is the name for the sliding scale that opens and closes the jaws (Fig1.14).

Reading a Vernier Caliper

CHECKING FOR ZERO ERROR	OBSERVED READING	CORRECTED READING
0 Main scale 1 0 Vernier scale 10 Two zero marks coincide No Zero error.	3 Main scale 4 0 Vernier scale 10 Reading=3.14cm	3.14cm (No zero error No correction required)
0 Main scale 1 0 Vernier scale 10 zero mark on vernier scale is slightly to the right Zero error is 0.03	3 Main scale 4 0 Vernier scale 10 Reading=3.17cm	3.17cm-(+0.03)=3.14cm (The positive zero error is subtracted from reading)
0 Main scale 1 0 10 Vernier scale Zero mark on vernier scale is slightly to the left. zero error of -0.07	3 Main scale 4 0 Vernier scale 10 Reading=3.11cm	3.11cm -(-0.07) =3.18cm (Negative zero error is added to the reading)

Micrometer Screw Gauge

Screw gauge in extensively used in engineering field for obtaining precision measurements. Micrometer screw gauge is used for measuring extremely small dimensions.

A screw gauge can even measure dimensions smaller than those measured by a Vernier Caliper. Micrometer Screw gauge works on the simple principle of converting small distances into larger ones by

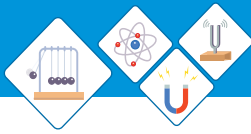



Fig 1.16 Screw Gauge

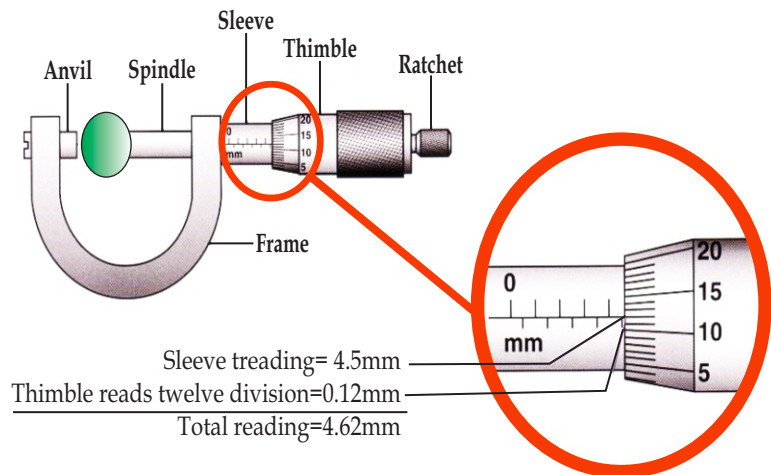
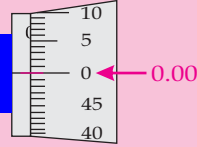
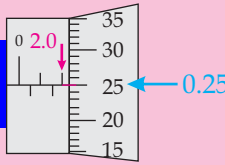
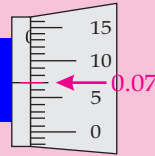
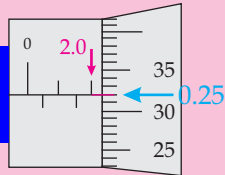
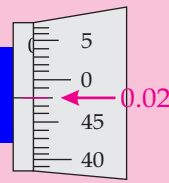
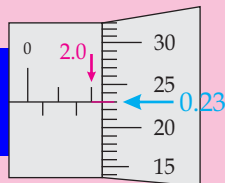
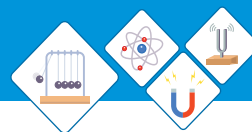
measuring the rotation of the screw. This "screw" principle facilitates reading of smaller distances on a scale after amplifying them (Fig 1.16).

Reading A Micrometer Screw Gauge

Step 1

Turn the thimble until the anvil and the spindle gently grip the object. Then turn the ratchet until it starts to click.

Step 2

Take the main scale reading at the edge of the thimble.

Step 3

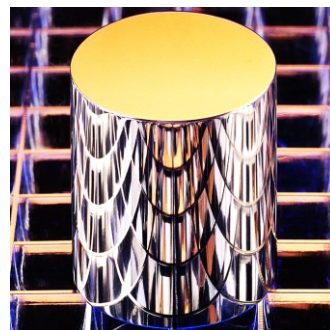
Take the thimble scale reading opposite the datum line of the main scale. Multiply this reading with least count i.e., 0.01mm

Step 4

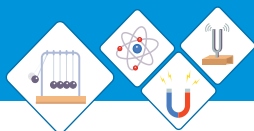
Now add main scale reading to thimble reading. This will be the diameter of the object.

Checking For Zero Error	Observed reading	Corrected Reading
10, 5, 0 ← 0.00, 45, 40 **Zero mark on thimble scale coincides with the datum line on the main scale and reading on the main scale is zero. No zero error**	0 2.0, 35, 30, 25 ← 0.25, 20, 15 **Reading = 2.0+0.25 = 2.25mm**	2.25mm No zero error No Correction is required
15, 10, 0.07, 5, 0 **Zero on** datum line can be seen. Positive Zero Error Reading =+0.07 mm **(Count from Zero.)**	0 2.0, 35, 0.25, 30, 25 Reading=2.0+0.32 =2.32mm	2.32 - (+0.07) =2.25mm
5, 0, 0.02, 45, 40 Zero mark on datum line cannot be seen negative zero error Reading= -0.02mm (count down from 0)	0 2.0, 30, 25, 0.23, 20, 15 Reading=2.0+0.23 =2.23mm	2.23 - (-0.02) =2.25mm

Do You Know!

The kilogram, originally defined as: The mass of one cubic decimeter of water at the temperature of maximum density.It was replaced after the International Metric Convention in 1875 by the International Prototype Kilogram.

The Standard Of Mass

The **kilogram** is the SI unit of **mass** and is equal to the mass of the international prototype of the kilogram, a platinum-iridium standard that is kept at the International Bureau of Weights and Measures (Fig1.17).

Fig 1.17 Kilo gram

Do You Know!

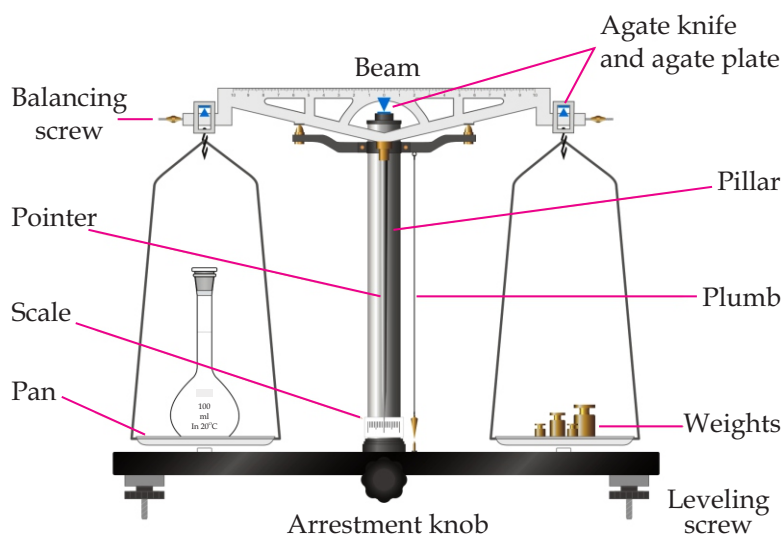
1000g = 1kg
1g = 1000mg
1g= 1000000µg
1g=1000000000ng
1g=0.002lb

The kilogram is a cylinder of special metal about 39 millimeters wide by 39 millimeters tall that serves as the world's mass standard.

Each country that subscribed to the International Metric Convention was assigned one or more copies of the international standards; these are known as National Prototype Meter and Kilogram.

The Physical Balance

Fig 1.18 Physical Balance

The **Physical balance** is an instrument used for measurement of mass. It is mostly used in laboratory. It works on the principle of moments. It consists of a light and rigid beam of brass, a metallic pillar, a wooden base, two pans, a metallic pointer and an ivory scale (Fig 1.18). The plumb line indicates whether the balance is horizontal. In ideal condition the plumb line is aligned with the end of the knob fixed with the pillar. When the beam is horizontal the pointer remains on zero mark on the ivory scale. The whole box has leveling screws at the bottom to set it to horizontal. The device is enclosed in a glass box to avoid wind effects.

The Electronic Balance

The digital mass meter is an electronic instrument configured with integrated circuits and it works on the principal of balancing the forces.
The device is turned on and set to zero then object is placed on the plate. The reading on the screen gives the mass of object. The electronic balance (Fig 1.19) is available in different ranges of measurement such as micro gram, milligram and kilogram etc.

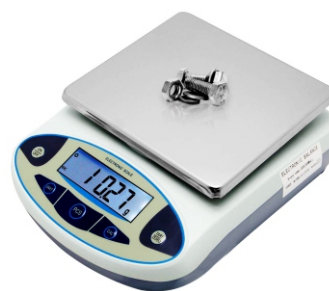



Fig 1.19 Electronic Balance

The Standard of Time

Before 1960, the standard of time was defined in terms of the mean solar day for the year 1900. The rotation of the Earth is now known to vary slightly with time, this motion is not a good one to use for defining a time standard.

In 1967, the **second** was redefined to take advantage of the high precision attainable in a device known as an atomic clock(Fig 1.20), which uses the characteristic frequency of the cesium-133 atom as the "reference clock".

Fig 1.20 Atomic Clock

The second is now defined as 9 192 631 770 times the period of vibration of radiation from the cesium atom.

Stop Watch

A stopwatch is used to measure the time interval between two events. There are two types of stopwatch : Mechanical stopwatch and Digital stopwatch.

Mechanical/ Analogue Stopwatch

A **mechanical stop** watch can measure a time interval up to 0.1 second (Fig1.21). It has a knob that is

Fig. 1.21 Stop Watch

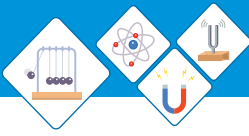
used to wind the spring that powers the watch. It can also be used as a start stop and reset button. The watch starts when the knob is pressed once. When pressed second time, the watch stops While the third press brings the needle back to zero.

Digital Stopwatch

Fig. 1.22 Digital stop watch

A digital stop watch can measure a time interval up to 0.01 second (fig 1.22). It starts to indicate the time lapsed as the start/stop button is pressed. As soon as start/stop button is pressed again, it stops and indicates the time interval recorded by it between start and stop of an event. A reset button restores its initial zero setting. Now a days almost the mobile phones have a stopwatch function.

Human Reaction Time

As analogue or digital or watch is operated by human manually i.e., they have to be started or stopped by hand. This causes a random error in measurement of time i.e called human reaction time. For most people human reaction time is about 0.3- 0.5 s. Therefore for more accurate measurement of time intervals light gates (Fig1.23) can be used.

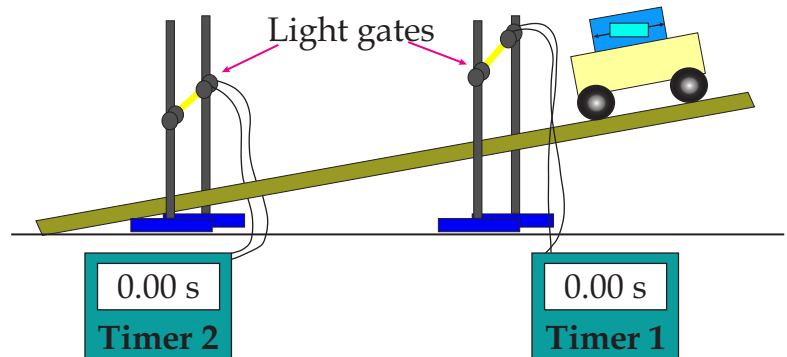
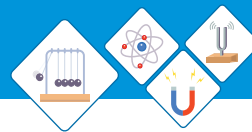



Fig 1.23 Light gates

SELF ASSESSMENT QUESTIONS:

Q1: What instrument will you choose to measure height of your friend?

Q2: Can you describe how many seconds are there in a year?

Q3: Which instrument will you choose to measure your mass?

1 hour = 60 min
1 hour = 3600 sec
1min=60sec
1sec=1000ms
1sec=1000000µs

1.3 PREFIXES

The Physical quantities are described by the scientist in terms of magnitudes and units. Units play a vital role in expressing a quantity either base or derived. Prefixes are useful for expressing units of physical quantities that are either very big or very small.

A **unit prefix** is a specifier. It indicates multiples or fractions of the units.

Units of various sizes are commonly formed by the use of such prefixes. The prefixes of the **metric system**, such as kilo and milli , represent multiplication by powers of ten. Historically, many prefixes have been used or proposed by various sources, but only a narrow set has been recognized by standards organizations.

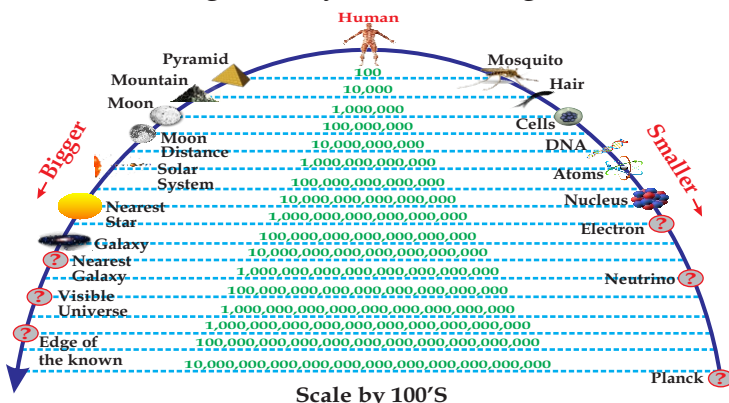
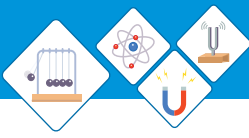
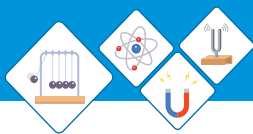



Table 1.3 SI pre fixes

SI Prefixes

Prefix	Symbol	Meaning	Multiplier (Numerical)	Multiplier (Exponential)
		Greater than 1		
tera	T	trillion	1 000 000 000 000	10^{12}
giga	G	billion	1 000 000 000	10^{9}
mega	M	million	1 000 000	10^{6}
kilo	k	thousand	1 000	10^{3}
hecto	h	hundred	100	10^{2}
deka	da	ten	10	10^{1}
		Less than 1		
Unit	**1**			
*deci	d	tenth	0.1	10^{-1}
*centi	c	hundredth	0.01	10^{-2}
*milli	m	thousandth	0.001	10^{-3}
*micro	μ	millionth	0.000 001	10^{-6}
*nano	n	billionth	0.000 000 001	10^{-9}
pico	p	trillionth	0.000 000 000 001	10^{-12}
femto	f	quadrillionth	0.000 000 000 000 001	10^{-15}
atto	a	quintillionth	0.000 000 000 000 000 001	10^{-18}

SELF ASSESSMENT QUESTION:

Q4: Can you tell if the size of a nucleus is up to 10^{-15}m. What prefix shall we use to describe its size?

1.4 SCIENTIFIC NOTATION

Scientific notation or the standard form is a simple method of writing very large numbers or very small numbers. In this method numbers are written as powers of ten. Thus calculation of very large or very small numbers becomes easy.

Numbers in Scientific Notation are made up of three parts: The coefficient, the base and the exponent.

- The coefficient must be equal to or (Not zero) greater than one
- The base must be 10
- The exponent can be negative or positive.

Worked Example 1

Convert mass of Sun 2 000 000 000 000 000 000 000 000 000 000 000 kg. into Scientific Notation.

Solution

Step 1: Since, M_{Sun} = 2 000 000 000 000 000 000 000 000 000 000 000 kg

It's obvious that in this value decimal lies at the end.

Step 2: Converting into scientific notation

Move the decimal to left writing in terms of base of ten

$M_{sun} = 2.00 \times 10^{30}$kg.

Note: power of exponent is taken as positive not to be confused as we have displaced decimals but not numbers.

Worked Example 2

Convert mass of an electron 9.11 x 10^{-31} kg into standard form.

Solution

Step 1: The decimal lies in the middle of the value.

Since, $m_{electron} = 9.11 \times 10^{-31}$ kg

Step 2: Move the decimal 31 steps towards left

$m_{electron}$ = 0.000 000 000 000 000 000 000 000 000 000 911 kg

1.5 DENSITY AND VOLUME

The three common **phases** or **states** of matter are **solid, liquid** and **gas**. A solid maintains a fixed shape and a fixed size, even if same force is applied it not readily change its volume. A liquid does not maintain a fixed shape it takes on the shape of its container. But, like a solid it is not readily compressible, and its volume can be changed significantly only by a large force.

Fill a tub with water to certain level and mark.

Put some ice in it and observe the water level carefully as well as floating or sinking.

Remove the ice from the tub without being melt and put a balloon in it and then observe.

Likewise, put a spoon in that tub and observe.

Again put an empty can of coke and observe.

Can you tell which of all four has more density? And which has more volume?

1 liter = 1000cm^3

1m^3 = 1000 litr

However, a gas has neither a fixed shape nor a fixed volume- it will expand to fill its container.
Often we find the large weight woods floating on the surface of water. However, an iron needle sinks into the water. We say iron is "heavier" than wood. This cannot really be true rather we should say like iron is "denser" than wood. Physicist are concerned with a physical quantity, a property of matter which may help to define the nature of matter in terms of its mass and space.

Measuring the Volume

For density to be measured or calculated we first need to find the volume of substances. Most of solid geometrical shapes have formulae for their volume which is obtained through different parameters such as radius, height, depth, width, base and length, but for irregular objects, liquids and gases this approach is unusual. The volume of liquids can be measured with the help of Cylinders, and Beakers.

Measuring Cylinder

Measuring cylinder is a glass or plastic cylinder with a scale-graduated in cubic centimeters or milliliters (ml)(fig1.24). It is used to find the volume of liquids. When a liquid is poured, it rises to a certain height in the cylinder. The level of liquid in the cylinder is noted and volume of the liquid is obtained.
In order to read the volume correctly we should keep the eye in level with the bottom of the meniscus of the liquid surface as you learned in previous grade.

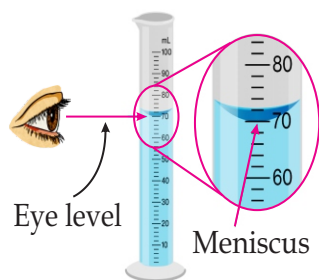
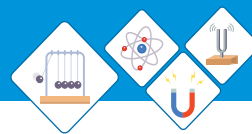



Fig. 1.24
Measuring Cylinder

1. Volume of Liquid

A volume of about a liter or so can be measured using a measuring cylinder. When the liquid is poured into the cylinder the level on scale gives the volume. Most measuring cylinders have scales marked in milliliters (ml) or cubic centimeters (cm^3). It should be noted that while recording the value from cylinder the eyes should maintain the level with the value. Angular observation may result a false reading of the volume.

2. Regular solid

If an object has a regular shape its volume can be calculated
For instance:
Volume of a rectangular block = length x width x height
Volume of a cylinder = $\pi \times \text{radius}^2 \times$ height

3. Irregular solid

For an irregular solid its volume is calculated by lowering the object in a partially filled measuring cylinder (fig 1.25). The rise in the level on the volume scale gives the volume of that object. Thus the volume of irregular solid is calculated by subtracting the original volume of liquid from the raised volume of liquid.

The total volume is found. The volume of the solid is measured in a separate experiment and then subtracted from the total volume.

Quick Lab

Take a measuring cylinder of 1 liter capacity at full place it in a beaker.

Fill cylinder full with water.

Pour a stone of irregular shape in it gradually.

As you pour the stone in the cylinder, the water from cylinder drops into the beaker.

Drop the stone in cylinder completely

Calculate the volume of water ejected out of cylinder.

Volume of water ejected is the volume of the stone.

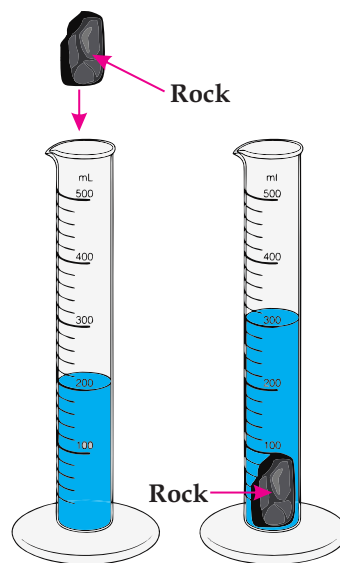
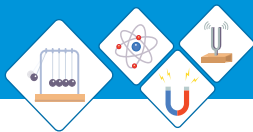



Fig 1.25. Volume Irregular shaped Solid

Density

The term **density** of a substance is defined as mass of substance (m) per unit volume (V). It is denoted by Greek letter **ρ (rho)**.

$$\rho = \frac{m}{V}$$

Do You Know!

During the Cold War between Russia and America. There was a race of Astrophysics. America was facing the period of racism. A Black lady mathematician named Katherine solved the problem of putting the first orbital satellite.
Recommended!
Watch movie "Hidden Figures"
Observe the importance of Reliable Numbers.

Density is characteristic property of any pure substance. Objects made of a particular pure substance such as pure Gold can have any size or mass but its density will be same for each.
In accordance with the above equation mass of a substance can be expressed as

$$m = \rho V$$

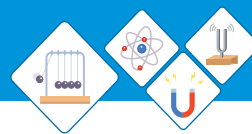
The S.I unit for density is kg/m^3 kgm^{-3}. Sometimes dens of substances is given in gm/cm^3. The density of Aluminum is 2.70 gm/cm^3 which is equal to 2700 Kg/m^3.

Do You Know!

In Jordan there is sea known as 'Dead Sea'
The humans in that sea while swimming does not sink!
This is because the water of sea is much more salty than normal, which raises the density of water.

Measuring the Density

It is to be noted that there are two ways of finding the density of a substance either mathematically or experimentally by taking density of water at 4°C as a reference which is sometimes known as relative density or **'Specific gravity'**. It has no unit, it is a number whose value is the same as that of the density in g/cm^3.

$$\text{relative density} = \frac{\text{density of substance}}{\text{density of water}}$$

Worked Example 4

What is the mass a solid iron wrecking ball of radius 18cm. if the density of iron is 7.8 gm/cm^3?

Solution:

Step 1: write known physical quantities with units and point out the quantity to be found.

Density of iron ball $\rho = 7.8\ gm/cm^3 = 7.8 \times 1000\ kg/\ m^3$

Radius of iron ball is $r = 18cm = 18 \times 10^{-2}\ m\ = 0.18m$

Volume of the iron ball is $V = (4/3) \times \pi \times r^3 = (1.33) \times 3.14 \times (0.18m)3\ V = 0.024m^3$

Step 2: write down the formula and rearrange if necessary

$m = \rho \times V$

Step 3: put the values in formula and calculate

Since mass of iron ball is $m = \rho \times V = (7.8 \times 10^3) \times (0.024)$

$m = 187.2\ kg$

SELF ASSESSMENT QUESTIONS:

Q5: How can you identify which gas is denser among the gases?

Q6: Can you tell how hot air balloon works?

1.6 SIGNIFICANT FIGURES

Engineers and scientist around the world work with numbers either representing a large or small magnitude of a physical quantity. The engineers are however interested in the accuracy of a value as they mostly work on estimation but scientist especially physicist are more concerned in the accuracy of these numbers. For instance, an engineer records the speed of wind and explains it on an average. On the other hand, for the physicist, the speed of earth on its course, the

speed of light in vacuum the mass or charge on an electron is just not a matter of numbers but accurate numbers.

The numbers of reliably known digits in a value are known as significant figures.

Table 1.4 Rules for determining significant figures

Rule	Example
1. All non-zeroes are significant	2.25 (3 significant figures)
2. Leading zeroes are NOT significant	0.00000034 (2 significant figures)
3. Trailing zeroes are significant ONLY if an explicit decimal point is present	200 (1 significant figure) 200. (3 significant figures) 2.00 (3 significant figures)
4. Trapped zeroes are significant	0.00509 (3 significant figures) 2045 (4 significant figures)

Worked example 5

How many significant figures are there in the area of a cylinder whose diameter is 5 cm

Solution:

Step 1: write known physical quantities and point out the unknown quantity

Diameter of the cylinder is $d = 5\text{cm} = 5 \times 10^{-2}\,\text{m} = 0.05\text{m}$

Radius of cylinder is $r = d/2 = 2.5 \times 10^{-2}\,\text{m} = 0.025\text{m}$

Step 2: write down formula and rearrange if necessary

The area of the cylinder is $A = \pi \times r^2 = 3.14 \times (0.025\text{m})^2 = 0.0019\text{m}^2$

Step 3: put value in formula and calculate

Thus area of cylinder can be written as $A = 1.9\ \text{mm}^2$

Thus, there are two significant numbers in the value 1 and 9.

SELF ASSESSMENT QUESTIONS:

Q7: Determine the number of significant figures in 00.6022009

SUMMARY

- Physics is the branch of science which deals with studies of matter its composition, properties, and interaction with energy.
- The branches of Physics are classified on the basis of different areas of study with different approaches.
- There are two types of physicist, theoretical and experimental physicist.
- Physics define mathematical relation between physical quantities. A physical quantity has magnitude and unit.
- Physical quantity are mainly classified into two categorize
  - (i) Base or fundamental quantities
  - (ii) Derived physical quantities.
- Base quantities are length, mass, time, temperature, current, luminous intensity, and amount of substance.
- The standard of length is meter can be measured by measuring tape , or meter rule.
- The standard of mass is kilogram can be measured by physical balance.
- The standard of time is second can be measured by stop watch.
- The measured or calculated values either macroscopic or microscopic can be expressed in Scientific Notations.
- The volume of liquid is calculated or measured with help of measuring cylinder

- The volume of irregular objects can be calculated through measuring cylinder with displacement of water.
- The density of a pure substance is its characteristic property it is the ratio of mass per unit volume.
- The density of objects can be calculated with the help of water as a reference known as specific gravity also known as relative density.
- Prefixes can be used to represent large or smaller values of a physical quantity.
- The most accurate or reliable numbers of a value are known as significant figures.

CONCEPT MAP

Physics Quantities
Based on its types, is divided into
Based on existing or has not direction, divided into
Base Quantities
There are
1. Length
2. Mass
3. Time
4. Temperature
5. Electric current
6. Luminous intensity
7. Amount of substance
Derived Quantities
For examples
Area
Volume
Force
Energy
Density
Scalar Quantity
For examples
Distance
Speed
Energy
Volume,
etc.
Vector Quantity
Displacement
Velocity
Work
Force

Physics Quantities
Length
Meter
Ruler/ Measuring Tape
Spring Balance/ Electronic balance/ Beam balance
Multiple Basic Sub multiple
km m mm
Mass
Kilogram
Multiple Basic Sub multiple
Metric Tone (t) kg mg
Time
Seconds
Stopwatch/clock
Multiple Basic Sub multiple
Min, hour Second (s) ms
Volume
Liter
Measuring cylinder/ flask/ beaker/pipette
Liter l Milliliter ml

End of Unit Questions

Section (A) Multiple Choice Questions (MCQs)

Fig 1.26

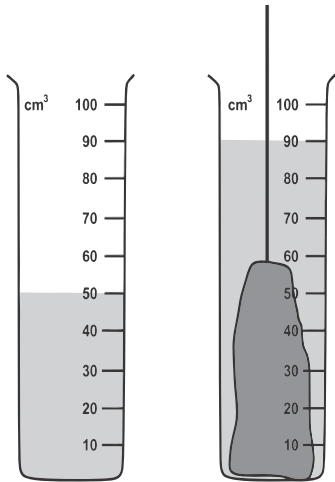



Fig 1.27

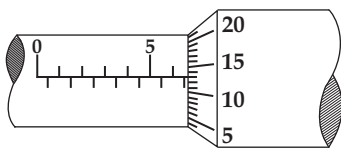



Fig 1.28

1. The Figure 1.26 shows part of a Vernier scale, what is the reading on the Vernier scale

   a) 6.50 cm b) 6.55 cm
   c) 7.00 cm d) 7.45 cm

2. Ten identical steel balls each of mass 27g, are immersed in a measuring cylinder having $20cm^3$ of water. The reading of water level rises to $50cm^3$. What is the density of the steel?

   a) $0.90\ gm/cm^3$ b) $8.1\ gm/cm^3$
   c) $9.0\ gm/cm^3$ d) $13.5gm/cm^3$

3. An object of mass 100g is immersed in water as shown in the figure 1.27, what is the density of the material from which object is made?

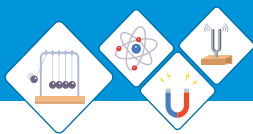
   a) $0.4gcm^3$ b) $0.9gcm^3$
   c) $1.1\ gcm^3$ d) $2.5gcm^3$

4. What is the reading of this micrometer in figure 1.28

   a) 5.43mm b) 6.63mm
   c) 7.30mm d) 8.13mm

5. A chips wrapper is 4.5 cm long and 5.9 cm wide. Its area upto significant figures will be

   a) $30\ cm^2$ b) $28\ cm^2$
   c) $26.55\ cm^2$ d) $32\ cm^2$

6. A worldwide system of measurements in which the units of base quantities were introduced is called
   a) prefixes
   b) international system of units
   c) hexadecimal system
   d) none of above
7. All accurately known digits and first doubtful digit in an expression are known as
   a) non-significant figures
   b) significant figures
   c) estimated figures
   d) crossed figures
8. If zero line of Vernier scale coincides with zero of main scale, then zero error is
   a) positive b) zero
   c) negative d) one
9. zero error of the instrument is
   a) systematic error b) human error
   c) random error d) classified error
10. Length, mass, electric current, time, intensity of light and amount of substance are examples of
   a) base quantities b) derived quantities
   c) prefixes d) quartile quantities

Section (B) Structured Questions

1.

Column A Action	Column B Branch
Cooking Bar B.Q	Thermodynamics
Turning the Bulb on	
Riding a bicycle	
Looking for Giant Galaxies	
Producing a loud sound	
Describing an atom	
Obtaining energy from Earth	

2.

Physical Quantity	S.I Unit	Type
Ampere		
	m^3	
	Sec	Base
Temperature		Base
	N	
Density	Kg per m^3	
Acceleration		

3. Convert the following values.

a) 230 cm = _______________m
b) 250 g = ______________kg
c) 0.5 s = _________________ms
d) 0.8 m = _____________mm
e) 350ms = _________________s
f) 1.2Kg = ______________g

4. An engineer measures the width of an aluminum sheet using Vernier caliper as shown in fig 1.29
   a) What is the measurement of the width of aluminum sheet
   b) Which gives more precise measurement Vernier caliper, Screw Gauge or meter rule?

Fig 1.29

5. A pendulum swings as shown if figure 1.30 from X to Y and back to X again
   i) What would be the most accurate way of measuring time for one oscillation? with the help of a Stop Watch.
      a) Record time for 10 oscillations and multiply by 10
      b) Record time for 10 oscillation and divide by 10
      c) Record time for one oscillation
      d) Record time from X to Y and double it
   ii) Suggest an instrument for measuring time period more accurately.

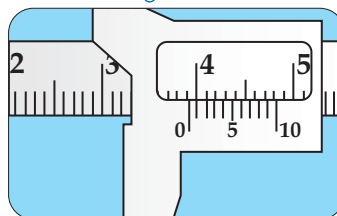
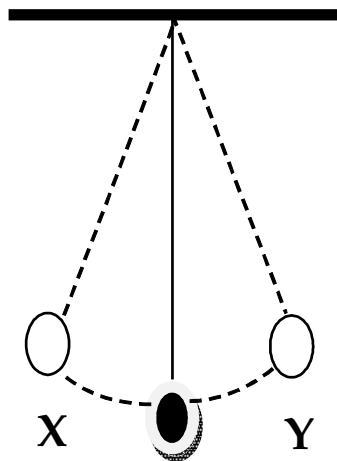
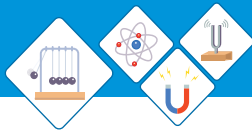
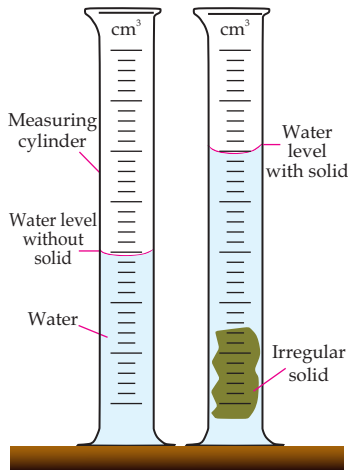



Fig. 1.30

Prefixes

6. write the correct prefix of notion
   a) 75000m = 750 __________
   b) 2/1000 sec = 1 __________
   c) 1/1000000 g = 1 __________
   d) 1000000000 m = 1__________

Scientific Notation

7. Write values in standard and scientific notation
   a) The radius of 1st orbit of Hydrogen atom is r = 0.53 A^0 = __________
   b) 1 light year is 2628000000000m = __________
   c) Vacuum pressure 2.7×10^{-4} torr = __________

Density and Volume

8. A wooden piece is made in different shapes take length (l) = radius (r) = 2m Calculate its volume as a:

a)	Sphere	b)	Cube
c)	Cylinder	d)	Pyramid
e)	Cylinder		

9. Find the density of wood as sphere and cube if the mass of wood is 1kg. Is there any change in density due to shape?

10. A measuring cylinder (fig 1.31) is filled with 500cc water. A stone of mass 20g is immersed in to the cylinder such that ,water level rises up to 800cc. Which statement is correct?
   a) The difference between the readings gives the density of stone.
   b) The difference between the readings gives volume of the stone
   c) The final reading gives the density of stone
   d) The final reading gives the volume of stone

Fig 1.31

Significant Figures

11. Write significant numbers in the following values.
   a) 980 has ________ Significant numbers.
   b) 91.60 has ________ Significant numbers.
   c) 10010.100 has ________ Significant numbers.
   d) 0.0086 has ______ Significant numbers.

KINEMATICS

The word Kinematics is derived from Greek Word kinema.
How an object changes its position in space in a certain time interval without considering the causes of motion it is the study of motion of bodies without any reference of force.

Students Learning Outcomes (SLOs)

After learning this unit students should be able to:

- Describe using examples how objects can be at rest and in motion simultaneously.
- Identify different types of motion i.e., translatory, (linear, random, and circular); rotatory and vibratory motions and distinguish among them.
- Define with examples distance, displacement, speed, velocity and acceleration (with units)
- Differentiate with examples between distance and displacement, speed and velocity.
- Differentiate with examples between scalar and vector quantities.
- Represent vector quantities by drawing.
- Plot and interpret distance-time graph and speed-time graph
- Determine and interpret the slope of distance-time and speed-time graph
- Determine from the shape of the graph, the state of a body (i) at rest (ii)moving with constant speed (iii) moving with variable speed
- Calculate the area under speed-time graph to determine the distance traveled by the moving body.
- Solve problems related to uniformly accelerated motion using appropriate equations
- To rearrange the equation according to the requirement of the problem
- Solve problems related to freely falling bodies using $10\ m/s^2$ as the acceleration due to gravity.

When you throw a ball straight up in the air, how high does it go? When a glass slips from your hand, how much time do you have to catch it before it hits the ground? How will you describe the motion of a jet fighter being catapulted down the deck of an air craft carrier? These and some other similar questions you will learn to answer in this unit.

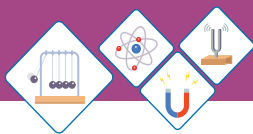
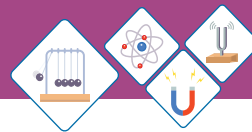



Fig 2.1, Car with respect to tree at rest position

The branch of physics which is related with the study of motion of objects is called Mechanics.

It is divided in two parts

(i) Kinematics (ii) Dynamics

The word kinematics is derived from Greek word "Kinema" which means motion.

Kinematics is the branch of Mechanics which deals with motion of objects without reference of force which causes motion.

2.1 REST AND MOTION

Have a look around in your classroom, You can observe various things like, table, chairs, books etc all are in state of rest. A car is in the state of rest with respect to trees and bushes around it Fig 2.1. Thus rest can be defined as:

Fig 2.2, Train at station

A body is said to be in rest if it does not change its position with respect to its surroundings.

A train is stationed at the platform. A person can notice that the train does not changes its position with respect to its surroundings, hence the train is in the state of rest Fig 2.2. But as soon as the train starts moving its position continuously changing with respect to its surroundings. Now we can say that the train is in motion. Thus motion can be defined as:

A body is said to be in motion if it changes its position with respect to its surroundings.

Rest and Motion are Relative State

No body in the universe is in the state of absolute rest or absolute motion. If a body is at rest with respect to some reference point at the same time, it can also be in the state of motion with respect to some other reference point.

Fig 2.3, A moving bus

For example, A Passenger sitting in a moving bus is at rest because passenger are not changing their position with respect to other passengers or objects in the bus as shown in fig 2.3. But for another observer outside the bus noticed that the passengers and objects inside the bus are in motion as they are changing their position with respect to observer standing at the road.

Similarly a passenger flying on aeroplane is in motion when observed from ground but at the same times he is at rest with reference to other passengers on board.

SELF ASSESSMENT QUESTIONS:

Q 1. Define Kinematics.

Q 2. When is a body said to be in state of rest?

Q 3. How are rest and motion related to each other?

2.2 TYPES OF MOTION

We observe around us that all objects in universe are in motion. However the nature of their motion is different, some objects move along circular path, other move in straight line while some objects move back and forth only. There are three types of motion.

(i) Translatory motion (linear, circular and random)

(ii) Rotatory motion

(iii) Vibratory motion.

(I) Translatory Motion

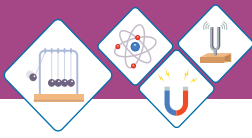
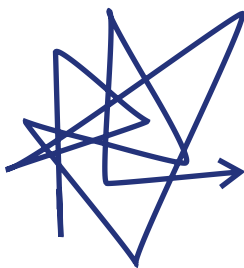



Fig 2.4 A train moving along a straight track

Different objects are moving around in different ways. You can observe how various objects are moving? Which objects move along a circular path? Which objects move along a linear path?

A train is moving along a straight track in Fig 2.4. you can observe that every part of the train is moving along that straight path.

This is called translatory motion. Translatory motion can be defined as:

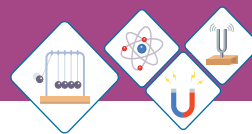
When all points of a moving body move uniformly along the same straight line, such motion is called translatory motion.

Fig 2.5 Moving bus

(a) Linear Motion:

We observe many objects moving along straight line. The motion of a bus in a straight line on road is called linear motion Fig. 2.5. Thus the linear motion can be defined as:

Motion of a body along a straight line is called linear motion.

Fig 2.6
An artificial satellite

(b) Circular Motion:

An artificial satellite moving around the Earth along circular path is an example of circular motion Fig 2.6. Thus circular motion can be defined as:

Motion of a body along a circular path is called circular motion.

Fig 2.7 Random motion

(c) Random Motion

You must have observed the motion of flies, insects and birds? They suddenly change their

direction. The path of their motion is always irregular. This type of motion is known as random motion . The random motion can be defined as :

Irregular motion of an object is called random motion.

The motion of butterfly, house fly, dust and smoke particles along zigzag paths are examples of random motion. The motion of the particles of a gas or a liquid known as the Brownian motion which is an example of random motion Fig2.7.

Fig 2.8 (a) Spinning top

Fig 2.8 (b) A wheel

(ii) Rotatory Motion

Have you noticed the type of motion of fan and spinning top? Every point of the top moves in a circle around a fixed axis. Thus every particle of the top possess circular motion Fig 2.8(a).
But the top as whole moves around an axis which passes through top itself so the motion of top is rotatory Thus rotatory motion can be defined as:

The motion of the body around a fixed axes which passes through body itself is called spin or rotatory motion.

Fig 2.8 (c) Ferris wheel

The motion of a wheel about the axle, the motion of a rider on the Ferris wheel are some examples of rotatory motion Fig 2.8 (a, b, c).

(iii) Vibratory Motion

Look at the motion of child in swing Fig 2.9(a). when swing is pulled away from its mean position and then released, the swing start moving back and forth about the mean position. This type of motion is called vibratory or oscillatory motion. Thus vibratory motion can be defined as:

Fig 2.9 (a) Motion of child in swing

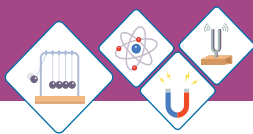



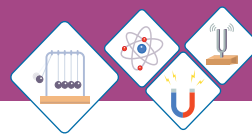
Fig 2.9 (b)
Clock's pendulum

Back and forth motion of a body about its mean position is called vibratory or oscillatory motion.

There are many examples of vibratory or oscillatory motion in daily life. for example, motion of the clock's pendulum Fig 2.9 (b).

Distinguish between Translatory, Vibratory and Rotatory

Translatory Motion	Rotatory Motion	Vibratory Motion
A body moves along a straight line.	The spinning of a body about its axis.	The body move back and forth about mean position.
Movement of an object from one place to another.	The motion of an object about fixed point.	The body moves up and down.
All particles of the rigid body move with the same velocity at every instant of time.	The motion of a rigid body about a fixed axis. Every particle of body move in a circular path	An object repeat its motion itself.

SELF ASSESSMENT QUESTIONS:

Q 4. Define Translatory Motion?

Q 5. What is vibratory motion?

Q 6. Differentiate between translatory motion, rotatory motion and vibratory motion.

2.3 DESCRIBING MOTION

The motion of an object can be described by specifying its position, change in position. speed, velocity and acceleration.

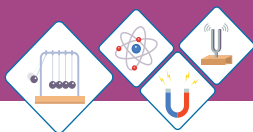
(i) Distance and Displacement

Fig 2.10
Distance and displacement

A person can use three different paths to move from place A to an other place B. It can be used to illustrate meaning of distance and displacement Fig 2.10.

What if the person moves back from B to A along any of the three paths. The person covers the distance is either 16 km (purple path) or 24 km (red path).
While the person is back at A so, the net displacement becomes zero.

Thus distance and displacement can be differentiated as follows:

Distance	Displacement
➢ The total length covered by moving body without mentioning direction of motion.	➢ The distance measured in straight line in a particular line.
➢ It is an scalar quantity.	➢ It is a vector quantity.
➢ The S.I unit is **metre (m).**	➢ The S.I unit is **metre (m).**
➢ The distance traveled by the person from A to B is either 16 km (purple path) or 24 km (red path)	➢ The displacement of the person is 6 km from A to B due west of A.

Do You Know!

Average speed of different animals and objects :

Animal /Object	Speed (kmh^{-1})
White-tailed deer	48
Ren deer	60-80
cheetah	100-120
Walking man	6
Grand prix car	360
Passenger jet	900
Sound	1200
Space shuttle	36000

(ii) Speed and Velocity

The speed of an object determines how fast an object is moving? It is rate of change of position of an object. There are many ways to determine speed of an object. These methods depend on measurement of two quantities.

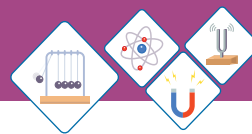
- The distance traveled
- The time taken to travel that distance

Thus the average speed of an object can be calculated as:

$$\text{Speed} = \frac{\text{distance traveled}}{\text{time taken}}$$

$$V = \frac{S}{t}$$

The equation for average speed in symbols can be written as :

$$V = \frac{S}{t} \quad \text{..............(eq 2.1)}$$

Where, "V" is the speed of the object, "S" distance traveled by it and "t"time taken by it. Thus average speed can be defined as:

Distance covered by an object in a unit time is called speed.

Fig 2.11
A racing car

The equation (2.1) gives only average speed of the body it can not be said that it was traveling with uniform speed or non uniform speed. For example, a racing car can be timed by using a stop watch over a fixed distance say, 500m Fig 2.11. Dividing distance by time gives the average speed, but it may speed up or slow down along the way. Speed is a scalar quantity and its S.I unit is ms^{-1}.

Uniform speed

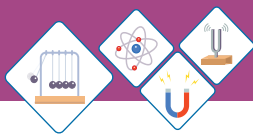
An object covers an equal distance in equal interval of time its speed is known as uniform speed.

Velocity

Velocity means speed of an object in a certain direction. Velocity is a vector quantity. thus velocity of an object can be defined as:

Rate of change of displacement with respect to time is called velocity.

$$\text{Velocity} = \frac{\text{Change in displacement}}{\text{time taken}}$$

$$\mathbf{v} = \frac{\Delta \mathbf{d}}{\mathbf{t}} \text{ ....} \mathbf{(2.2)}$$

Here **d** is displacement of the moving object, **t** is time taken by object and **v** is velocity. SI unit of velocity is ms^{-1}.

The velocity of an object is constant when it moves with constant speed in one direction. The velocity of object does not remain constant when it changes direction with out changing its speed, or it changes speed with no change in direction. Thus average velocity of an object is given by

$$\text{Velocity} = \frac{\text{total displacement}}{\text{total time taken}}$$

Uniform velocity:

A body is said to have uniform velocity if it cover equal distance in equal interval of time in a particular direction .

Worked Example 1

A car travels 700m in 35 seconds what is the speed of car?

Solution

Step 1: Write the known quantities and point out quantities to be found.

$d = 700m$

$t = 35s$

$v = ?$

Step 2: Write the formula and rearrange if necessary.

$$v = \frac{d}{t}$$

Step 3: Put the value in formula and calculate

$$v = \frac{700}{35} = 20ms^{-1}$$

Thus the average speed of car is $20ms^{-1}$.

Worked Example 2

The speed of train is $108\ kmh^{-1}$. How much distance will be covered in 2 hours?

Solution

Step 1: Write the known quantities and point out quantities to be found.

$$v = \frac{108\ km}{h} = \frac{108 \times 1000\ m}{3600\ s} = 30ms^{-1}$$

$$t = 2h = 2 \times 3600s = 7200s$$

$$d = ?$$

Step 2: Write the formula and rearrange if necessary

$$v = \frac{d}{t}$$

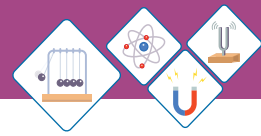
$$d = v \times t$$

Step 3: Put value in formula and calculate

$$d = 30 \times 7200 = 216000m$$

Thus distance traveled by train is 216000m.

Acceleration

Fig 2.12 (a)
Velocity of this car is increasing

An object accelerates when its velocity changes. Since velocity is a vector quantity so it has both magnitude and direction. Thus acceleration is produced when ever:

- Velocity of an object changes
- Direction of motion of the object changes,
- Speed and direction of motion of the object change.

Thus acceleration can be defined as:

Rate of change of velocity of an object with respect to time is called acceleration.

$$\text{Acceleration} = \frac{\text{change in velocity}}{\text{time taken}}$$

$$a = \frac{\Delta v}{t} \qquad \because \Delta v = v_f - v_i$$

$$\therefore \quad a = \frac{v_f - v_i}{t} \quad \text{...............(eq 2.3)}$$

Fig 2.12 (b)
Velocity of this car is decreasing

Acceleration is a vector quantity. Its SI unit is metre per second per second (**ms^{-2}**).

When velocity of an object increases or decreases with passage of time, it causes acceleration. The increase in velocity gives rise to positive acceleration Fig 2.12(a). It means the acceleration is in the direction of velocity. Whereas acceleration due to decrease in velocity is negative and is called **deceleration** or *retardation* Fig 2.12(b).The direction of deceleration is opposite to that of change velocity.

Uniform Acceleration

A body has uniform acceleration, if the velocity of body changes by an equal amount in every equal time period.

When the change i.e., increase or decrease in the velocity of an object is same for every second then its acceleration is uniform. when velocity of an object is increasing by 10 ms^{-1} every second ,the acceleration is $10ms^{-2}$.When the velocity of the object is decreasing by $10ms^{-1}$ every second, the deceleration is 10 ms^{-2}. Thus, uniform acceleration can be defined as:

A constant rate of change of velocity is called uniform acceleration.

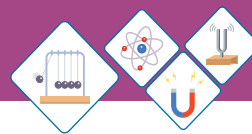
The uniform acceleration can be calculated by using following formula :

$$\vec{a} = \frac{\Delta\vec{V}}{\Delta t} = \frac{\vec{v}_f - \vec{v}_i}{t_2 - t_1}$$

Where **v_f**= initial velocity (in ms^{-1});
v_i= final velocity (in ms^{-1});
t_1= time at which an object is at initial velocity u (in s);
t_2 = time at which an object is at final velocity v (in s);
Δ**v**= change in velocity (in ms^{-1})
Δ**t**= time interval between t_1 and t_2(in s)

Worked Example 3

A bus start from rest and travels along a straight path its velocity become $15ms^{-1}$ in 5 seconds. Calculate acceleration of the bus?

Solution:

Step 1. Write the known quantities and point out quantities to found.

v_i = 0 ms^{-1}
v_f = 15 ms^{-1}
t = 5 second
a = ?

Step 2: Write the formula and rearrange if necessary

$$a = \frac{v_f - v_i}{t}$$

Step 3: Put the value in formula and calculate.

$$a = \frac{15 - 0}{5} = \frac{15}{5} = 3ms^{-2}$$

Acceleration of bus is $3ms^{-2}$.

Worked Example 4

A motorcyclist moving along a straight path applies breakes to slow down from $10ms^{-1}$ to $3ms^{-1}$ in 5 seconds. Calculate its acceleration.

Solution

Step 1. Write the known quantities and point out quantities to be found.

$v_i = 10ms^{-1}$

$v_f = 3ms^{-1}$

$t = 5$ second

$a = ?$

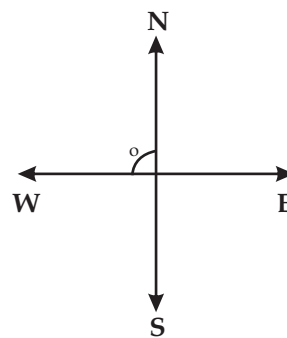
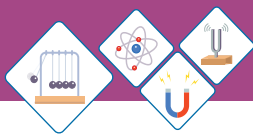
Step 2. Write the formula and rearrange if necessary.

$$a = \frac{v_f - v_i}{t}$$

Step 3: Put the value in formula and calculate.

$$a = \frac{3 - 10}{5} = \frac{-7}{5} = -1.4\ ms^{-2}$$

Deceleration of motorcycle is $-1.4\ ms^{-2}$.

The negative sign shows the retardation in opposite direction of velocity.

Self Assessment Questions:

Q 7. Define Speed.

Q 8. What is velocity?

Q 9. Define acceleration.

2.4 SCALARS AND VECTORS

All physical quantities are divided into two types on the bases of information required to describe them completely.

- Scalars
- Vectors

Scalars

There are certain physical quantities that can be described through their magnitude and a suitable unit. This information is enough to describe them, For example the mass of a watermelon is 3kg, where 3 is the magnitude and kg is a suitable unit such quantities are called scalar quantities. Thus we can define **scalar** quantities as:

The physical quantities that have magnitude and a suitable unit are called scalar quantities.

The other examples of scalar quantities are speed, temperature, mass, density etc.

Vectors

Some physical quantities need direction along with their magnitude and unit for their complete description. For example, a bus traveling with a velocity of $50ms^{-1}$ in the direction of North. The vector quantities can be defined as:

The physical quantities which are completely specified by magnitude with suitable unit and particular direction are called as "Vector" quantities.

Force ,acceleration , momentum, torque and magnetic field are the examples of vector quantities

SELF ASSESSMENT QUESTIONS:

Q 10. Define Vector.

Q 11. Differentiate between vector and scalar quantities.

Representation of vector:

Vector diagram is an easy way to represent a vector quantity. The directed line segment can be used to represent a vector. The length of the line segment gives the magnitude of the vector and arrow head gives its direction. For example, Fig 2.14 represents velocity of a car travailing at $50ms^{-1}$ in the direction of 30° North of East.

N
W
E
S
$50ms^{-1}$
30°

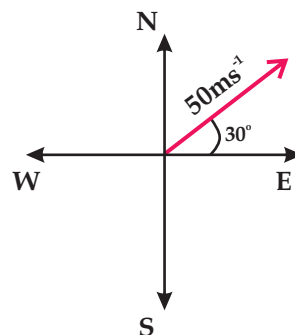



Fig. 2.14

2.5 GRAPHICAL ANALYSIS OF MOTION

Graph gives the complete information about the motion of the object based on the measured physical quantities such as distance, speed, time etc.

Distance - Time Graphs

A bus travels along a straight road from one bus stop to another bus stop. The distance of the bus from first bus stop is measured every second. The possible motion of the bus is shown by three examples.

The vertical axis gives rise of the graph while horizontal axis shows its run. The rise divided by run is called **gradient.**

The gradient on the distance time graph is numerically equal to the speed.

When bus travels with uniform speed, the distance time graph is a straight line. Fig 2.15(a) shows graph of the motion of bus with steady speed, the line rises 5 m on the distance scale for every 1 seconds on the time scale.

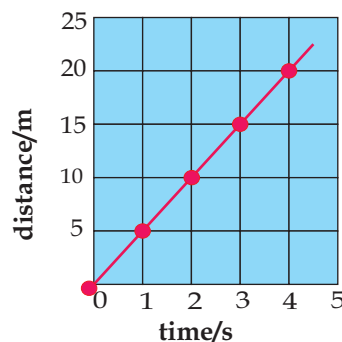



Fig. 2.15 (a)
Uniform speed

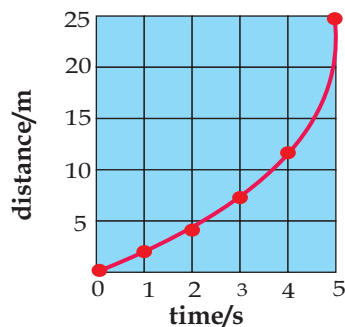



Fig.2.15 (b)
Non-uniform speed

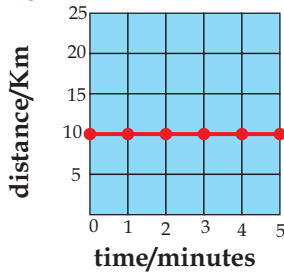
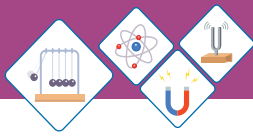



Fig.2.15 (c)
Objective at rest

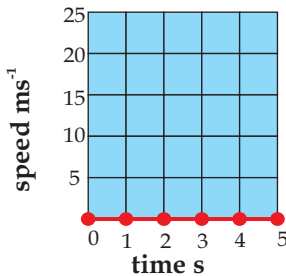



Fig. 2.16 (a)

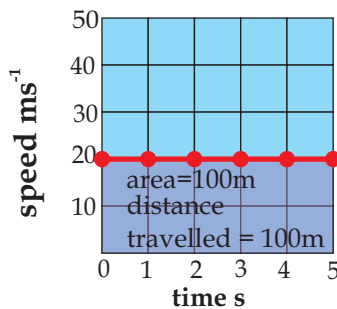



Fig.2.16 (b)

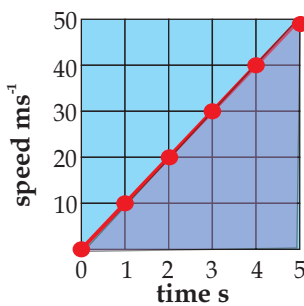



Fig 2.16 (c)

$$\text{Gradient} = \frac{20}{4} = 5$$

Thus speed = 5 ms^{-1}.

when bus travels with non-uniform speed, the distance time graph is a curve. Fig 2.15(b) shows motion of the bus, for this case the speed rises every second. So the bus covers more distance each second than the one before.

When the bus stops on the next bus stop to drop or pick the passengers the time continues running but the distance stays same. The graph line is now parallel to the time axis which shows the bus does not change its position Fig. 2.15(c).

Speed -Time Graph

Speed -time graph tells us that how much speed is increasing or decreasing in every second. Thus,

The gradient on speed - time graph gives the acceleration of the moving object.

If the gradient is positive then acceleration is also positive. On the other hand, if gradient is negative then acceleration will be negative which is known as deceleration or retardation.

In graph Fig.2.16(a), the bus is at rest for an interval of 5 seconds. Therefore, speed of bus remains zero for entire interval of time.

Fig.2.16(b), the bus moves at steady speed 20 ms^{-1} for 5 second, so the distance covered is 100 m. The distance is always product of speed and time, therefore two magnitudes on speed-time graph ($20 \times 5 = 100$) determine the distance represented through shaded rectangle on the graph Fig 2.16 (b).

Now suppose that once again bus is accelerated as the speed of bus increases at the rate of 5 m every second, the distance covered in next 5 seconds is determined by shaded triangle on the graph Fig 2.16 (c).

The area of shaded triangle, $\frac{1}{2}$ (base × height). So the distance travelled is 75 meters.

On a speed -time graph, the area under the line is numerically equal to the distance travelled.

2.6 EQUATIONS OF MOTION

There are three basic equations of motion for bodies moving with uniform acceleration. These equations are used to calculate the displacement (s), velocity, Time (t) and acceleration (a) of a moving body.

Suppose a body is moving with uniform acceleration "a" during some time interval "t" its initial velocity "v_i" changes and denoted as final velocity "v_f". The covers a distance "s" in this duration of time.

First Equation of Motion

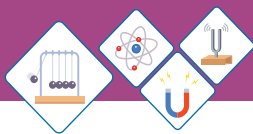
In First equation determine the final velocity of a uniformly accelerated body.

where v_f = Final Velocity

v_i = Initial Velocity

a = acceleration

t = time

The average acceleration is the change in velocity over a time interval

$$a = \frac{\text{change in velocity}}{\text{time}}$$

$$a = \frac{v_f - v_i}{t}$$

$$at = v_f - v_i$$

$$\therefore \quad v_f = v_i + at \quad \cdots\cdots\cdots\cdots (2.5)$$

This is known as the first equation of motion.

Second Equation of Motion

The second equation of motion determines the distance covered during some time internal "t", while a body is accelerating from a known initial velocity.

As we know the average velocity $= \dfrac{v_f + v_i}{2}$

Putting value of v_f from equation 2.5 we get

$$\text{Average velocity} = \frac{(v_i + at) + v_i}{2}$$

$$= \frac{v_i + v_i + at}{2}$$

$$= \frac{2v_i + at}{2}$$

$$= \frac{2v_i}{2} + \frac{at}{2}$$

$$= v_i + \frac{1}{2}at$$

As the $s = vt$ or $v = \dfrac{s}{t}$

$$\frac{s}{t} = v_i + \frac{1}{2}at$$

$$\therefore s = v_i t + \frac{1}{2}at^2$$

This equation is known as second equation of motion

$$S = v_i t + \frac{1}{2}at^2 \text{..............}(2.6)$$

Third Equation of Motion

Third equation of motion determines relationship among the velocity and the distance covered by a uniformly accelerated body, where time interval is not mentioned.

Let us take the first equation of motion.

$$v_f = v_i + at$$

By squaring the both sides of equation we get:

$$v_f^{\,2} = (v_i + at)^2$$

or $$v_f^{\,2} = v_i^{\,2} + 2v_i at + a^2t^2$$

or $$v_f^{\,2} = v_i^{\,2} + 2a(v_i t + \frac{1}{2}at^2)$$

According to second equation of motion $S = v_i t + \frac{1}{2}at^2$

Therefore $$v_f^{\,2} = v_i^{\,2} + 2a(S)$$

$$2aS = v_f^{\,2} - v_i^{\,2} \quad \text{..............(2.7)}$$

This is known as third equation of motion for bodies moving with uniform acceleration.

Worked Example 5

A car moving on a road with velocity 30 ms^{-1}, when brakes are applied its velocity decreases at a rate of 6 meter per second.

Find the distance it will cover before coming to rest.

Solution

Step 1: Write the known quantities and point out quantities to found.

$a = -6\ ms^{-2}$

$v_i = 30\ ms^{-1}$

$v_f = 0$

$S = ?$

Step 2: Write the formula and rearrange if necessary.

$$2aS = \frac{v_f^{\,2} - v_i^{\,2}}{2a}$$

$$S = \frac{v_f^{\,2} - v_i^{\,2}}{2a}$$

Step 3: Put value in formula and calculate

$$S = \frac{(0)^2 - (30)^2}{2 \times (-6)}$$

$$S = \frac{-900}{-12} = 75m$$

Thus the car will stop after covering 75m distance.

Worked Example 6

A motor cycle moving with velocity of 40 ms^{-1}. It gets accelerating at a rate of 8 ms^{-2}. How much distance will it cover in the next 10 seconds.

Solution

Step 1: Write the known quantities and point out quantities to found.

$v_i = 40\ ms^{-1}$

$a = 8\ ms^{-2}$

$t = 10s$

$S = ?$

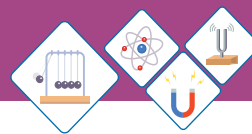
Step 2: Write the formula and rearrange if necessary

$$S = v_it + \frac{1}{2}at^2$$

Step 3: Put value in formula and calculate

$$S = 40 \times 10 + \frac{1}{2} \times 8 \times (10)^2$$

$$S = 400 + \frac{1}{2} \times 8 \times 100$$

$$S = 400 + \frac{800}{2}$$

$$S = 400 + 400m$$

$$S = 800m$$

Thus motor cycle covers 800 m in next 10 seconds.

2.7 MOTION DUE TO GRAVITY :

If two stones of different sizes are dropped from same height simultaneously, which of them will hit the ground first? You can observe that lighter and lighter stone catch the same accelerated and hit the ground at same time.

To discover this Galileo Galilei carried out a series of experiments from at leaning tower Pisa and carefully observed that all objects catch the same acceleration due to gravity of earth. The mass or size of object has no effect. It was against the widely accepted claim of Aristotile that heavier objects would fall faster than lighter one. A small feather and a stone are dropped in an air filled tube. Since air resistance greatly affects the feather, so the stone falls faster; Fig 2.18. On the other hand, when feather and stone are dropped in absence of air resistance, they acquire the same acceleration and reach the bottom at same time..

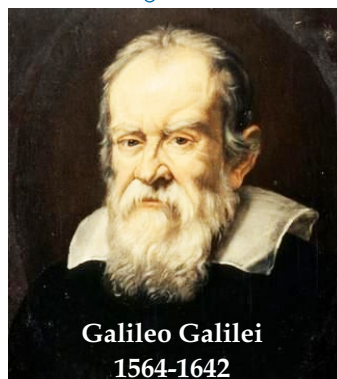



Fig 2.17

Acceleration due to gravity 'g' is a constant. Its value near the surface of earth is found to be 9.81 ms^{-2}. However for ease of calculation value of 'g' is approximated to 10 ms^{-2}.

Gravitational acceleration is taken negative for objects moving downward and positive for objects moving upward.

Fig 2.18

A piece of feather and a piece of stone dropped together in an air filled glass tube (a) and an evacuated air free glass tube (b)

For the motion of bodies under the influence of gravity the equation of motion are slightly modified. Where distance is taken as (S=h) and acceleration is taken as g (a=g).

There fore equation of motion are taken as.

(i) $v_f = v_i + gt$

(ii) $S = v_i t - \frac{1}{2} gt^2$

(iii) $2gh = v_f^{\,2} - v_i^{\,2}$

Worked Example 7

A ball is thrown vertically upward with velocity of 12 ms^{-1}. The ball will be slowing down due to pull of Earth's gravity on it, and will return back to Earth.
Find out the time the ball will take to reach the maximum height.

Solution

Step 1: Write the known quantities and point out quantities to be found.

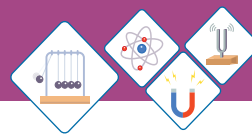
$v_i = 12\ ms^{-1}$

$v_f = 0\ ms^{-1}$

$g = -10\ ms^{-2}$

$t = ?$

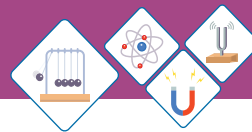
Step 2: Write the formula and rearrange if necessary.

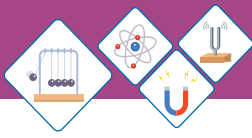
$$v_f = v_i + gt$$

$$t = \frac{v_f - v_i}{g}$$

Step 3: Put the value in formula and of calculate.

$$t = \frac{0 - 12}{-10}$$

$$t = 1.2\ s$$

The ball will reach maximum height in 1.2 seconds.

SUMMARY

- A body is said to be at rest if it does not change its position with respect to its surroundings.
- A body is said to be in motion if it changes its position with respect to its surroundings.
- When all points of moving body move uniformly along the same straight line the motion is called translatory motion.
- Motion of a body along straight line is called linear motion.
- Motion of a body along a circular path is called circular motion.
- Irregular motion of an object is called random motion.
- The motion of the body around a fixed axis which passes through body itself is called spin motion.
- Back and forth motion of a body about its mean position is called vibratory of oscillatory motion.
- The total length covered by moving body without mentioning direction of motion is called distance.
- The distance measured in straight line in a particular direction is called displacement.
- Distance covered by an object in a unit time is called speed.
- An object covers an equal distance in equal interval of time is called uniform speed.
- Rate of change of displacement with respect to time is called velocity
- Rate of change of velocity of an object with respect to time is called acceleration.

- The gradient on the distance time graph is numerically equal to the speed.
- The physical quantities that have magnitude and suitable unit are called scalar quantities.
- The physical quantities completely specified by magnitude in suitable unit and particular direction are called vector.
- The motion under gravitational force of Earth is always directed towards Earth.
- The value of 'g' is taken as $10ms^{-2}$.

kinematics

Describing motion without reference if causes

Rest

No change in position relative to surrounding

Motion

Change in position relative to surrounding

Translatory motion

Rotatory or Spin motion

Vibratory motion

Linear motion

Circular motion

Random motion

Distance

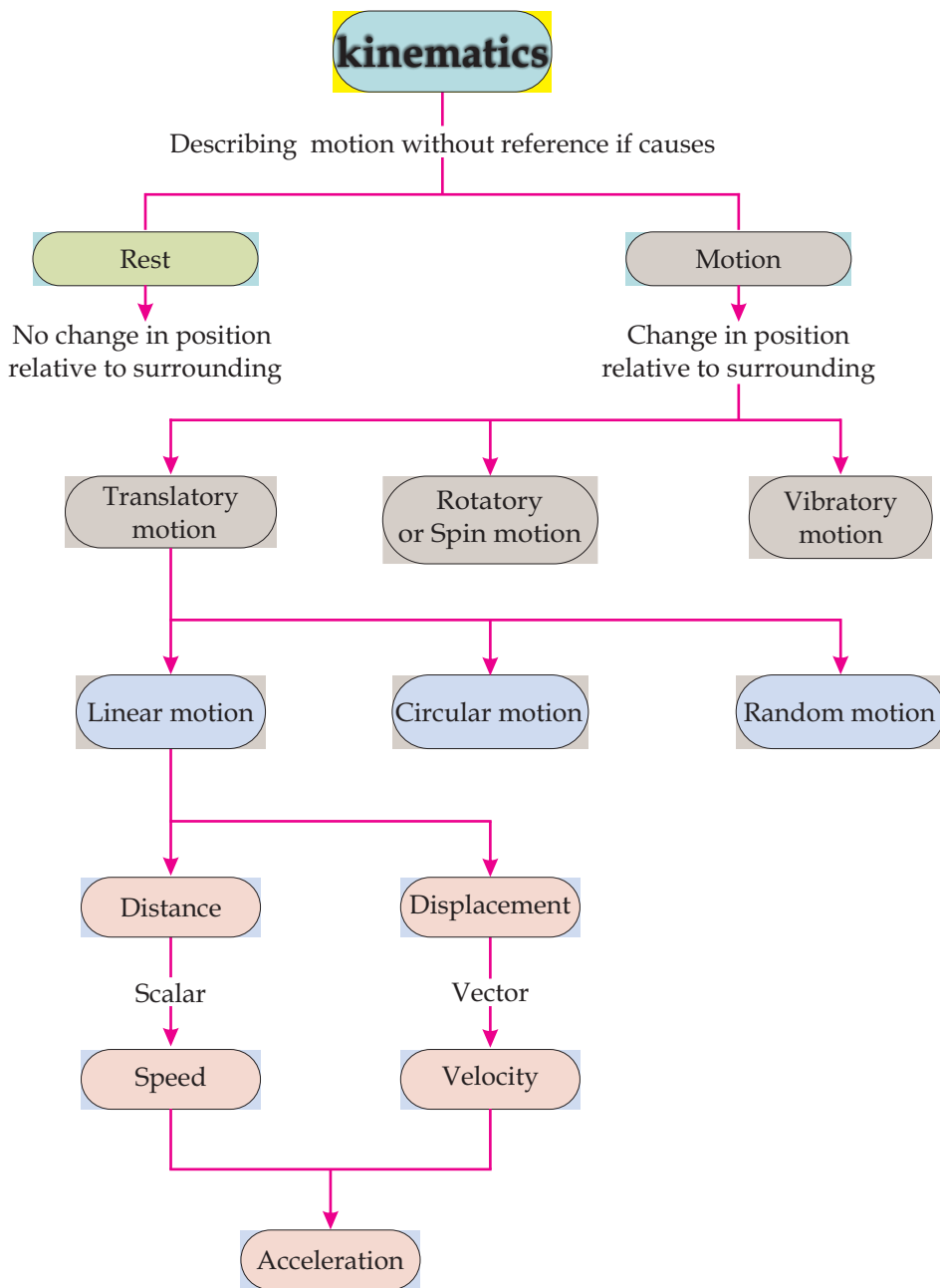
Scalar

Speed

Displacement

Vector

Velocity

Acceleration

End of Unit Questions

Section (A) Multiple Choice Questions (MCQs)

1. Scalar Quantities have .... and suitable unit.
   a) magnitude b) direction c) both a and b
2. Vector quantities have .... along with magnitude and unit.
   a) Magnitude b) direction c) both a and b
3. Which one is a vector quantity ....
   a) Mass b) Weight c) time
4. Which one is a scalar Quantity............
   a) time b) Force c) Velocity
5. Distance is a ....quantity.
   a) Vector b) Scalar c) both a and b
6. What is SI unit of acceleration
   a) ms^{-1} b) ms^{-2} c) nm
7. What is a SI Unit of Velocity.............
   a) Nm b) ms^{-1} c) ms^{-2}
8. Shortest distance between two points is called
   a) distance b) speed c) displacement

Section (B) Structured Questions

Rest and motion

a) Define rest and motion.
b) What is meant by relative motion.

Types of motion

a) Define speed and velocity
b) What is difference between distance and displacement.

c) Define acceleration

d) Calculate the acceleration of a bus that speed up from $20ms^{-1}$ to $40ms^{-1}$ in 8 seconds.

Scalars and vectors

a) Define scalar and vector quantities?

b) How represent vector quantities are represented graphically?

Equation of motion

a) A bus is moving on a road with $15ms^{-1}$ and it accelerates at $5ms^{-2}$. Find the final velocity of bus after 6 seconds.

b) A car starts moving from rest with an acceleration of $5ms^{-1}$. Find out the time to travel 50m distance.

Motion due to gravity

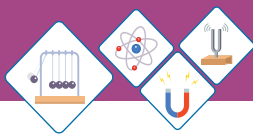
a) Define motion under gravity?

b) Why gravity is taken negative for an object moving in upward direction?

c) A ball is dropped from a height of 50m. What will be its velocity before touching ground?

d) If a body is thrown up ward with vertical velocity $50ms^{-1}$. Calculate maximum height which body can reach.

e) A ball falls down from top of height of 70m. How much time the ball will take to reach the ground.

Unit - 3

DYNAMICS

Dynamics is the study of cause of motion. In common force is cause of motion. Several other factors like mass of the object and frictional force also affect the motion of an object. These factors are also studied under dynamics. Newton's laws of motion has good deal with such factors, hence these laws govern the factors affecting the motion of body and help understanding the dynamics.

Students Learning Outcomes (SLOs)

After learning this unit students should be able to:

- Define momentum with SI unit.
- Calculate momentum using equation $p = mv$
- Define law of conservation of momentum.
- Use the principle of conservation of momentum in the case of collision of two objects.
- Solve problem using the equation Force = change in momentum / change in time.
- Identify the safety devices (such as packaging of fragile objects, the action of crumple zones and seatbelts) utilized to reduce the effects of changing momentum.
- State Newton's laws of motion.
- Distinguish between mass and weight
- Solve problem using $F = ma$, and $w = mg$
- Explain the forces acting on a body moving on a curved path.
- Calculate the centripetal force on a body moving along a circular path using mv^2/r .
- Define friction.
- Explain the effect of friction on the motion of a vehicle in the context of tyre surface, road conditions including skidding, braking force.
- Identify the relationship between load and friction by sliding a trolley carrying different load with the help of a spring balance on different surfaces.
- Demonstrate that rolling friction is much lesser than sliding friction.

What causes a body to change its speed? What causes the cricket ball to change its direction from wicket to boundary line? When you stop paddling your bicycle it does not stop at once. Why? After learning this unit you will be able to answer these and some other similar questions.

Do You Know!

- Force is required to change the position, state or shape of an object.
- Force can act as pull or push agent.
- Force produces acceleration.
- It can produce distortion.
- Force is a vector.

Force

Force is the agent that changes the state of rest or uniform motion of a body.

Its SI unit is Newton (N)

One Newton (1 N) is the amount of force that can produce 1 ms^{-2} acceleration in 1 kg mass.

An object (Fig 3.1)at rest needs a force to get moving; a moving object needs a force to come in rest or change its velocity or direction. The magnitude of a force can be measured using a spring balance.

Fig 3.1
Force moves or tends to move a body from state of rest.

Activity

Take a cardboard box (Fig 3.2). Connect it to a spring balance through a string. Pull the string and note down the reading of the spring balance. How much force is required to make it moving? Put a few book on the box. Now pull the string until the box starts moving. Note down the reading on spring balance.
Again put many books on the box and pull it. Fill your observations in the table 3.1 below and discuss with your colleagues.

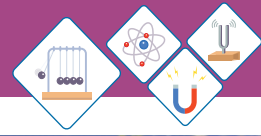
Fig. 3.2

Table 3.1

Case	Force required	Discussion
Empty box		
Few books on box		
Many books on box		

3.1 MOMENTUM

Fig. 3.3

Fig 3.4
A man trying to stop a truck by pulling it from back

If a cricket ball(Fig3.3) and a car are moving with same speed, which one is easier to stop it with hands? Why it is not possible for a person to stop even a slow moving truck(Fig 3.4) by pulling from backside?
The momentum depends upon the quantity of mass and velocity of the object. Greater the mass greater will be momentum. Similarly faster the speed greater will be momentum.
In terms of an equation,

The momentum of an object is equal to the mass multiplied by the velocity of the object.

$$\text{Momentum} = \text{mass} \times \text{velocity}$$

Symbolically, the momentum is represented by **p**. Thus, the above equation can be written as

$$\mathbf{p = mv} \quad \text{---------------} \quad (3.1)$$

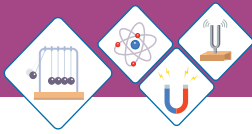
where m is the mass and v is the velocity. The momentum is vector quantity.

SI Unit of Momentum

A mass unit is multiplied by a velocity unit to provide a momentum unit. This is consistent with the equation for momentum. The SI unit of momentum is describe below,

$$\text{Momentum} = \text{mass} \times \text{velocity}$$
$$= kgms^{-1}$$
$$= kgms^{-2} \times s$$
$$\text{or} \quad = Ns \quad \text{(Newton second)}$$

Do You Know!

The pull of gravity on:
a fly = 0.001N
an apple = 1N
The frictional force slowing a rolling football =2N
The force required to squash an egg =50N
The tension in a rope towing a car = 1000N (1kN)
The fractional force exerted by the brakes of a car = 5000N (5kN)
The push from the engines of a space rocket =1000000N (1MN)

Do You Know!

Momentum is defined as quantity of motion contained in a body. Momentum is product of mass and velocity of a moving object. Hence it is mass times the velocity (**p = mv**).

Worked Example 1

A car of mass 800 kg is moving with velocity of 2 ms^{-1}. Its momentum can be calculated as;

Solution

Step 1: Write the known quantities and point out quantities to be found.

$m = 800\ kg$

$v = 2ms^{-1}$

$p = ?$

Step 2: Write the formula and rearrange if necessary.

$p = mv$

Step 3: Put the values in formula and calculate.

$p = 800kg \times 2ms^{-1}$

$p = 1600\ kgms^{-1}$

Thus, momentum of the car is $1600kgms^{-1}$.

Worked Example 2

A 60kg object is moving at a velocity of 5 meters per second. What is its momentum?

Solution

Step 1: Write the known quantities and point out quantities to be found.

Mass of object $m = 60\ kg$

Velocity of object $v = 5\ ms^{-1}$

Momentum $p = ?$

Step 2: Write the formula and rearrange if necessary.

$p = mv$

Step 3: Put the values in formula and calculate.

$p = (60\ kg) \times 5ms^{-1}$

$p = 300\ kgms^{-1}$

Thus, the momentum of object is $300kgms^{-1}$.

Momentum in terms of force:

We can also say that the change in momentum is equal to the force multiplied by the time interval for which it was applied. Consider a body of mass **m**, moving with initial velocity $\mathbf{v_i}$. A force **F** acts on the body to produce acceleration **a**, therefore the final velocity after time **t** will become $\mathbf{v_f}$. Note that if **p = mv** and **m** is constant, then the change in velocity changes the momentum of body.

$$p_i = mv_i$$

$$p_f = mv_f$$

and $p_f - p_i = (mv_f - mv_i)$ change in momentum

$p_f - p_i = m(v_f - v_i)$ divide both sides by t

$$\frac{p_f - p_i}{t} = m\frac{v_f - v_i}{t}$$

Since rate of change of velocity is acceleration

$$\frac{v_f - v_i}{t} = a \quad \text{Therefore} \quad \frac{p_f - p_i}{t} = ma$$

according to Newton's second law of motion F=ma therefore,

$$\frac{p_f - p_i}{t} = F$$

$$\Delta \mathbf{p} = \mathbf{Ft} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.2)$$

Safety devices:

The equation (3.2) is important when it comes to consider a number of safety features in our lives. If you are moving, you have momentum. To stop moving, a force must be applied. According to the equation (3.2) if you take longer time to stop, smaller force will be used to slow down you.

Observe a car to identify the safety measures taken to reduce the risk of injuries in case of road accident. The car bumpers and grills are designed to provide extra time to reduce speed before any collision.

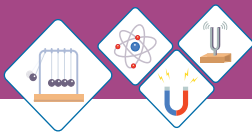



Fig 3.5 Styrofoam

Worker Helmet

Motorbike Helmet

Sports Helmet

Fig 3.6 Different safety helmets

You can find some crumple zones or bumpers on front and backside. Seat belts are provided to hold the passengers from moving suddenly. There are extra cushions and air bags as well. These measures provide extra time to change momentum of the passenger inside it. This means that force acting on the passenger is less to prevents from risk of fatal injuries.

Fragile objects, glassware and sensitive electronic components are packed in safety bags and Styrofoam(Fig 3.5) packing to reduce the effect of sudden shock.

The helmets protect from direct strike on head and provide extra time to reduce speed before something strikes to it.

Different safety helmets are used by workers, riders and sportsmen (Fig 3.6).

Worked Example 3

Find the force that can stop a body to rest in 4 seconds from its initial velocity of 16 ms^{-1}. The mass of body is 3kg.

Solution

Step 1: Write the known quantities and point out quantities to be found.

$m = 3\,kg$

$v_f = 0\,ms^{-1}$

$v_i = 16\,ms^{-1}$

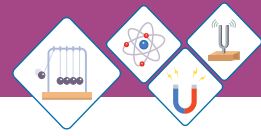
$t = 4$ second

$F = ?$

Step 2: Write the formula and rearrange if necessary.

$p_i = mv_i$

$p_f = mv_f$

$$F = \frac{p_f - p_i}{t}$$

Step 3: Put the values in formula and calculate

Now $p_i = 3kg \times 16\ ms^{-1}$

$= 48\ Ns$

$p_f = 5kg \times 0ms^{-1}$

$= 0\ Ns$

Since $F = \frac{p_i - p_f}{t}$

$F = \frac{0Ns - 48Ns}{4s}$

$F = -12\ N$

Thus, 12 N force is required in opposite direction to stop the body.

Law of Conservation of Momentum:

The concept of momentum is important particularly in situations when two or more bodies are interacting with each other. It is very useful quantity when it comes to calculate what happens in collision or explosion. It is always conserved when the colliding bodies are in an **isolated system**. This means that when bodies collide no external forces act on the bodies.

Thus law of conservation of momentum states that

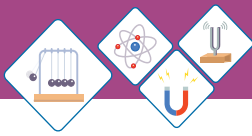
"The total momentum of an isolated system always remains constant"

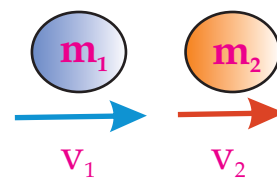
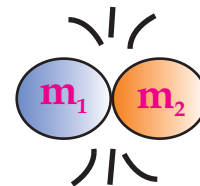
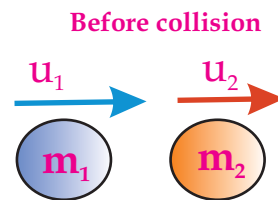
For simplicity consider a system of two billiard balls of mass m_1 and m_2 moving in straight line with velocities u_1 and u_2 respectively where u_1 is greater than u_2 (Fig 3.7).

Total momentum of the system before collision = $m_1u_1+m_2u_2$

After collision the velocities become v_1 and v_2 respectively, therefore

Total momentum after collision = $m_1 v_1 + m_2 v_2$

According to law of conservation of momentum:

$$\begin{bmatrix}\text{Total momentum of the} \\ \text{system before collision}\end{bmatrix} = \begin{bmatrix}\text{Total momentum of the} \\ \text{system after collision}\end{bmatrix}$$

thus, $\mathbf{m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2}$ ------ (3.3)

Before collision

After collision

Fig 3.7

Worked Example 4

A gun of mass 8 kg fires a bullet of mass 40 gram with a velocity of 100 ms^{-1}. Calculate the recoil velocity of gun.

Step 1: Write the known quantities and point out quantities to be found.

Mass of gun $m_1 = 8\,kg$

Mass of bullet $m_2 = 40\,gram = 40/1000 = 0.04\,kg$

Before collision

Velocity of bullet $u_2 = 0\,ms^{-1}$

Velocity of gun $u_1 = 0\,ms^{-1}$

After Collision

Velocity of bullet $v_2 = 100\,ms^{-1}$

Velocity of gun $v_1 = ?$

Step 2: Write the formula and rearrange if necessary.

$$m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$$

or $$m_1 u_1 + m_2 u_2 - m_2 v_2 = m_1 v_1$$

$$v_1 = \frac{(m_1 u_1 + m_2 u_2) - m_2 v_2}{m_1}$$

Step 3: Put the values in formula and calculate

$$v_1 = \frac{(8kg \times 0ms^{-1} + 0.04kg \times 0ms^{-1}) - (0.04kg \times 100ms^{-1})}{8kg}$$

$$v_1 = -0.5\,ms^{-1}$$

The gun will recoil with velocity of 0.5 ms^{-1} Here -ve sign show the recoil in opposite direction.

Fig 3.8 (a) A table in the state of rest

Self Assessment Questions:

Q1: Why momentum is considered equal to zero when a body comes to rest?

Q2: Why do you pull your hands while catching a fast moving ball?

3.2 NEWTON'S LAW OF MOTION

First Law of Motion

You have often observed the table placed in your classroom . It always remains at the same place until you apply some force to move it. Like a book placed on the table remains at its place unless someone picks it back. Similarly, a satellite in the space continuously moves with constant speed because there is no air or force of friction in the space.

Contrary to above examples, a ball rolling on the ground however stops after some time because friction of ground and air resistance exert force on it and change its state of motion or direction of motion. We can define **Newton's first law of motion** as

A body continues its state of rest or of uniform motion in a straight line unless an external force acts on it.

The Newton's first law is also called law of inertia. You may have sometimes observed that you put your bag on the seat next to you. Whenever the bus stops suddenly, the bag slides forward off the seat. Why does it happen?

The bag was initially moving forward because it was on a moving bus. When the bus stopped, the bag continued moving forward, which was its initial state of motion, and therefore it slid forward off the seat.

Inertia:

Inertia is the property of an object due to which it tends to continue its state of rest or motion. Inertia is resistance to change the state.

When a bus starts moving the passengers feel a backward jerk, because their lower part of body moves

Issac Newton
1642-1727

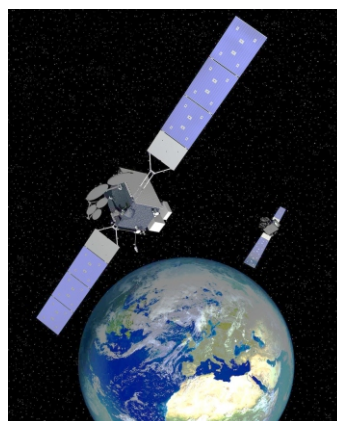
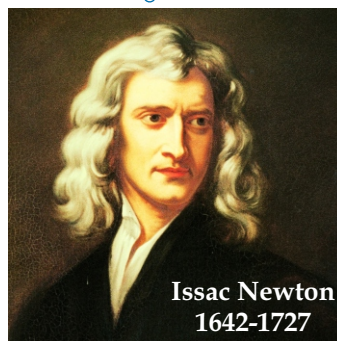
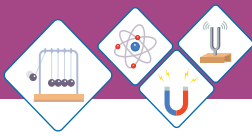



Fig 3.8 (b) A satellite in state of continuous motion around the earth.

along the motion of bus but the upper part of the body tends to stay at its initial position of rest.

On the other hand when you stop paddling your bicycle it does not stop at once. The bicycle continues moving. However the road's friction and air resistance act against its motion and bring it to rest after some time.

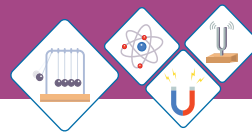
Fig 3.9(a)

Fig 3.9(b)

Activity

Coin and card activity is very common to observe the property of inertia of a body.
You need a glass, a card and a coin.
Place the card on the glass.
Place the coin at center of card (Fig 3.9a)
Now flick the card with a jerk of finger
What did you observe?
The card moves away from the glass(Fig 3.9b).
Did the coin move away?
Why did the coin fell in the glass?
The coin tends to stay at rest.
The coin resisted to change in its state of rest.

Do You Know!

Newton's Laws of motion were published in Latin language in 1687. The first law of motion was written as "Lex I: Corpus omne perseverare in statu suo quiescendi vel movendi uniformiter in directum, nisi quatenus a viribus impressis cogitur statum illum mutare"

Self Assessment Questions:

Q3: What is reason that you experience a jerk whenever the school bus stops all of sudden?

Q4: Why it is dangerous to jump from a moving bus?

Second Law of Motion

Find few marbles of different size. Select one marble of very small size and another one larger about double the mass of first marble. Predict that by hitting with same force which marble will be accelerated more.

Now try hitting the marbles one by one with third marble with same force. You may observe that the smaller marble catches almost double the acceleration as compared to bigger marble. Can you explain this phenomena?

Newton's second law of motion describes the relation between force and acceleration. Newton's second law of motion states that;

"when a net force acts on a body it produces acceleration in the direction of force. The acceleration is directly proportional to force and inversely proportional to mass of body".

Therefore,

$$a \propto F$$

$$a \propto \frac{1}{m}$$

$$a \propto \frac{F}{m}$$

putting the proportionality constant k,

$$a = k\frac{F}{m}$$

$$Fk = ma$$

taking value of constant k =1,

$$\mathbf{F = ma} \quad ....3.4$$

Weblinks

Teacher should encourage learners to visit following website to observe supportive information

- http://www.quia.com/jq/19675.html
- http://csep10.phys.utk.edu/astr161/lect/history/newton3laws.html
- http://www.istp.gsfc.nasa.gov/stargaze/Snewton.htm
- http://www.walter.fendt.de/ph11e/n2law.htm

Worked Example 5

Find the force that can accelerate a body of 50 kg mass up to 5 ms^{-2}.

Solution

Step 1: Write the known quantities and point out quantities to be found.

$m = 50\ kg$

$a = 5\ ms^{-2}$

$F = ?$

Step 2: Write the formula and rearrange if necessary.

$$F = ma$$

Step 3: Put the values in formula and calculate

$$F = 50kg \times 5ms^{-2}$$

$$F = 250 \ N$$

Thus the force is 250N.

Worked Example 6

Find the force that stops a car of 1000 kg mass from its velocity of 72 km/h over a distance of 40 meters.

Solution

Step 1: Write the known quantities and point out quantities to be found.

$m = 1000 \, kg$

$v_i = 72 \, km/h = 72 \times 1000/3600 = 20 \, ms^{-1}$

$v_f = 0ms^{-1}$ as the car comes to rest

$S = 40 \, m$

$a = ?$

$F = ?$

Step 2: Write the formula and rearrange if necessary.

$$2aS = v_f^2 - v_i^2$$

$$a = \frac{v_f^2 - v_i^2}{2S}$$

and $F = ma$

Step 3: Put the values in formula and calculate

$$a = \frac{(0ms^{-1})^2 - (2ms^{-1})^2}{2 \times 40m}$$

$$a = -5 \, ms^{-2}$$

Now

$$F = m \, a$$

$$F = 1000 \, kg \times -5ms^{-2}$$

$$F = -5000 \, N$$

Thus an opposing force of 5000N acts on the car.

Mass and Weight

Mass is the actual amount of material contained in a body and is measured in kg. Whereas weight is the force exerted by the gravity on that object (w= mg). Mass is independent of everything but weight is different on the earth, moon, and other places due to difference of gravitational pull.

Mass is the amount of matter present in a body while weight is a measure of how strongly gravity pulls on that matter. Mass is an intrinsic property of the body and remains the same wherever the body might be. Weight is a force, (Force = mass x acceleration). The weight of an object is the mass times the acceleration due to gravity.

The weight of the body differs from place to place. For example, objects weigh lesser on the moon where gravity is lower as compared to that on the Earth.

Comparison Chart	Mass	Weight
Definition	Mass is the quantity of matter in a body regardless of its volume or of any forces acting on it.	Weight is a measurement of the gravitational force acting on an object.
Effect of gravity	Mass is always constant at any place.	The weight of an object depends on the gravity at that place.
Unit of Measurement	Mass is measured in kilogram (kg)	Weight is measured in Newton (N)

(a) Beam balance

(b) Spring balance

(c) Electronic balance

Fig 3.9

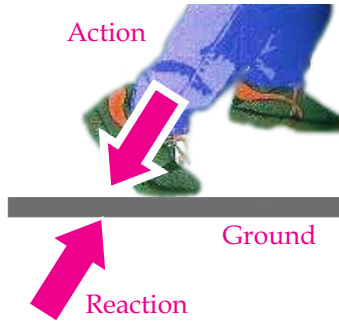
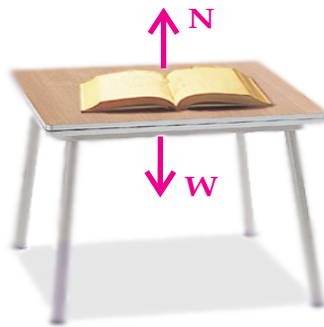



Fig 3.10 (a)

Balance used for measurement	Mass is measured using a pan balance, a triple-beam balance, lever balance or electronic balance.	Weight is measured using a spring balance.

Newton's Third Law of Motion

This law describes what happens when a body exerts a force on another body. Many times you through a ball towards wall and it bounces back. If it is thrown with greater force the ball is returned back with greater push. It is because the wall reacts against the action of ball.

While walking on ground you push the ground with feet the ground pushes you back thus you move (Fig. 3.10 a). As these forces always occur in pairs, so when one body pushes against another, the second body pushes back just as hard.

Fig 3.10 (b)

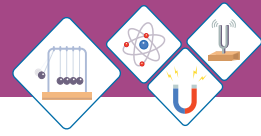
For example, when you put a book on table the book pushes the table downward, the table pushes back the book upward (Fig 3.10 b). Thus Newton's third law of motion can be defined as:

> To every action, there is an equal and opposite reaction.

The action and reaction are forces that occur together as a pair. They are always equal in quantity but opposite in direction.

While standing on ground the gravity pulls you down against the ground, the ground pushes up against your feet.

Fig 3.10 (c)

When a rocket ignites its fuel behind it, the expanding exhaust gas pushes on the rocket causing it to accelerate (Fig 3.10 c).

SELF ASSESSMENT QUESTIONS:

Q5: What is role of force according to Newton's second law of motion?

Q6: What happens according to Newton's third law, while you pull a catapult?

Q7: Why mass does not differ, while weight differs from place to place?

3.3 UNIFORM CIRCULAR MOTION

Take a smaller bucket, tie a piece of string to its handle. Hold the other end of string and rotate the bucket in vertical circle (Fig 3.11). You may feel some pull on your arm. Now put few coins in the bucket, again rotate it. It is amazing the coins do not fall even the bucket goes bottom up. More interesting will be the experimenting with some water. Pour about a cup of water in the bucket. Now try rotating the bucket around and up. How interesting it is? The water stuck to the bottom of bucket. The force that keeps it stuck is known as centrifugal force and the force you apply against the pull on your arm is known as centripetal force.

Fig 3.11

Centripetal Force

The force required to move a body along a circular path is called Centripetal force.

It is denoted by F_c. The centripetal force is always directed towards center of the circular path. It depends on three factors: (i) the velocity of the object v (ii) the object's distance from the center "r" and (iii) the mass of the object "m". It is given by relation

$$F_c = \frac{mv^2}{r} \quad \text{.......................} \quad (3.5)$$

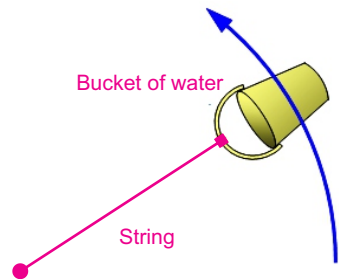
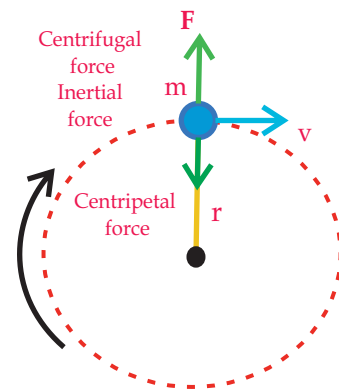



Fig3.12
Centripetal and centrifugal forces acting on an object.

Where m = mass of body moving in circle.

v = velocity of body.

r = radius of circle

The velocity of the object is constant and perpendicular to a line running from the object to the center of the circle.

Worked Example 7

A cyclist is making a turn along a circle of radius 20 m, at a speed of 5 m/s. If the combined mass of the cyclist plus the cycle is 60 kg, calculate the static friction that road exerts on the tyres?

Solution

Step 1: Write the known quantities and point out quantities to be found.

$r = 20\,m$

$v = 5\,ms^{-1}$

$m = 60\,kg$

$F = ?$

Step 2: Write the formula and rearrange if necessary.

$$F_c = \frac{mv^2}{r}$$

Step 3: Put the values in formula and calculate

$F_c = 60\,(5 \times 5)/\,20$

$= 60 \times 25/20$

$= 75\,N$

Thus road must exert a force of 75N on tyres.

Centrifugal Force

Centrifugal force is the tendency of an object to leave the circular path and fly off in a straight line. Thus it is defined as:

A force that acts outward on a body which moves along a curved path is called centrifugal force.

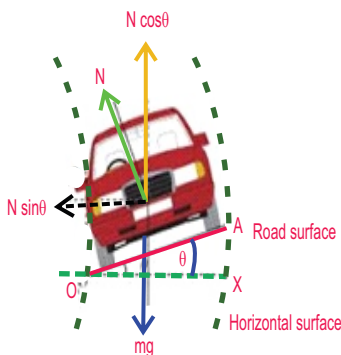



Fig 3.13

- It is always directed away from center of curvature.
- The magnitude of centrifugal force is equal but opposite in direction to centripetal force.

Application of Centrifuge

Centrifuge appliances are used to separate heavier particles from lighter particles in liquids e.g. Sugar crystals are separated from molasses. Blood analysis is carried out through a centrifuge process in laboratory. Cream separator is used to separate the cream from skimmed milk. An ultracentrifuge is used for separating small particle from large molecules. Gas centrifuge is used for separation of isotopes.

Road Banking

The outer edge or bank of the road is raised to a certain height at the curved part of roads. This provides the centripetal force against the tyres of vehicle hence prevents from skidding (Fig 3.13).

Cream Separator

The milk plants in country are using high speed spinners to separate cream from milk. The skimmed milk is heavier whereas the cream is lighter. When the milk is spun at high speed the heavy particles are pushed towards the walls of the spinner. These particles push the lighter particles of cream to the center where from it is collected through a tube (Fig 3.14).

Fig 3.14
Cream separator

Dryer

Now a days built-in dryer is available in most of washing machines. It spins the wet clothes hence the

water droplets are thrown away from the perforated walls of the dryer and clothes get dry instantly Fig 3.15.

Fig 3.15, Dryer

Self Assessment Questions:

Q8: Why do we feel pushed outward while a car turns on a curved road?

Q9: Which force prevents a passenger from falling down a roller coaster while it turns the riders into upside-down position?

3.4 FRICTION

When you through a ball why does it come to rest?When we kick a ball and a box with same force why the ball covers more distance? Well! in previous grades you came to know that friction helps us walk easily, it prevents from sliding but sometimes it has disadvantages as well.

Friction is a contact force caused by the roughness or deformation of the materials in contact. The frictional force between a wooden block and cemented floor caused by the roughness of both the surfaces is projected in Fig. 3.16. Frictional forces are always parallel to the plane of contact between two surfaces and opposite to the direction of the applied force.

Fig. 3.16 Projection of Roughness of surfaces.A wooden block and cemented floor

The force that resists relative motion between two surfaces is called friction.

Friction is self adjusting. It can increase to a certain value known as limiting force (F_s). It is proportional to normal force R.

$$F_s \propto R$$

The ratio between limiting force and normal reaction R is constant that is represented by coefficient of friction μ

Thus, $\mathbf{F_s = \mu R}$ .... (3.6)

Table 3.2
Value of coefficient of friction for different surfaces.

Surfaces	Value
Tyre and Road	1.0
Iron and Iron	1.0
Glass and Glass	0.9
Wood and Cemented floor	0.6
Wood and Marble	0.4
Wood and Leather	0.4
Wood and Wood	0.3
Metal and Metal	0.3

or $$\mu = \frac{F_s}{R}$$

when a body is placed on a surface its weight w acts downward then according to Newton's third law of motion R = W, here w = mg by putting the value R = mg in eq. (3.6) we get

$$\mathbf{F_s = \mu\, mg} \quad \text{........ (3.7)}$$

The coefficient of friction has different values for different surfaces as shown in the table 3.2.

Activity

Let us experience difference of friction on different surfaces.

You need a wooden block, a spring balance, connecting strings and few weight slots (Fig 3.17).

Put a 1 kg slot on the block.

Pull it across the wooden table, note down the reading from spring balance.

Now put 3 kg weight on the block, again pull it and note the reading. Similarly put the 5 kg weight on block and note down the reading in the observation table.

Now repeat the experiment with different surfaces.

Note down the reading for glass surface, cemented floor and carpeted floor. Now put few piece of pipes under the wooden block and repeat the activity. Observe how rolling friction is lesser than sliding friction.

Fill the table3.3 below with observations then discuss the difference of force of friction in each case.

Also discuss the use of ball bearings in vehicles.

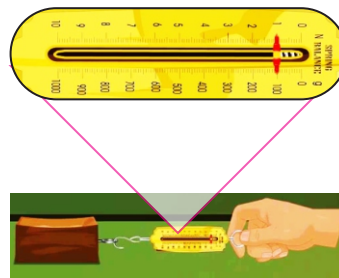



Fig 3.17

Table 3.3

Surface	Reading for Load on Wooden Block		
	1kg	3kg	5kg
Cemented floor			
Carpeted floor			
Glass surface			
Wooden Table			
Rolling on pieces of pipes			

Types of Friction

Static friction

It is force acting on an object at rest that resists its ability to start moving. The maximum static friction is known as "limiting friction"

Weblinks

Supportive information Web link about friction

http://www.phy.ntnu.edu.tw/java/friction/friction.html

Kinetic friction

It is the force that resists the motion of a moving object. It is interesting to know that in almost all situations, static friction is greater than kinetic friction.

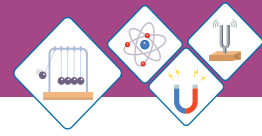
Do You Know!

Safety ramps are constructed along roadside where failure of brakes is feared due to sharp inclination of road.

Sliding friction

When one body slides over the other body the friction between two surfaces is said to be sliding friction.

Rolling friction

When a body moves on wheels the friction is said to be rolling friction. Rolling friction is much lesser than the sliding friction.

In case of rolling friction the contact area between two surfaces is lesser than the contact area in case of sliding bodies. Therefore ball bearings are used in vehicles that they reduce the contact area as compared to the contact area of axel and bush. A pedestal fan with ball bearing saves a lot of electricity therefore the customers always select a fan with ball bearing rather than one with bush and axel.

Advantages of Friction

Friction enables us to walk on ground. Friction protects from sliding, as sand is thrown to maintain friction on inclined railway tracks during rain. The car brakes slow down the car to stop safely. Threads and grooves are designed on tyres to increase the friction and improve grip between road and wheel (Fig 3.18 a). Now vehicles are equipped with Anti-lock Braking System (ABS). ABS is designed to maintain steering stability, improve vehicle control, avoid skidding and decreases stopping distances on dry and slippery surfaces. The ABS maintains the static friction as the wheel starts slipping it releases the brake automatically for a fraction of a second then holds wheel again to create static friction between road and tyres (Fig 3.18 b).

Fig. 3.18 (a) Tyre Grooves improve grip on road

Disadvantages of Friction

A large amount of energy is wasted in the machines due to friction.

Friction leads to wear and tear of parts hence increases the service cost.

Failure of oil pump in car engine results contact between dry metals which yields high temperature hence the car engine is seized.

Fig 3.18 (b) You might have noticed a logo on some cars

Fig 3.18 (c) Ball Bearings reduce friction

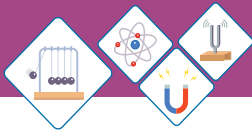
Fig 3.18 (d) Lubricating the bicycle chain

Ways to reduce Friction

Wheels, pullies, ball bearings, lubricants and graphite are used to overcome the friction; Fig 3.18 (c). Lubricating the motor axel, sewing machine and bicycle chain reduces friction and prevents wear and tear; Fig 3.18 (d). The shape of vehicle is also designed to reduce air resistance.

Self Assessment Questions:

Q10: Why it is easier to walk wearing flat slippers than the high heel sandals?

Q11: Why leather sheet is used in brake drums of motor bike?

- Dynamics is the study of cause of motion. In common force, mass of the object and frictional forces affect the motion of an object.
- Force is the agent that changes the state of rest or motion of a body. It can accelerate a body.
- Momentum is defined as quantity of motion contained in a body. Momentum is product of mass and velocity of a moving object.
- Newton's first law of motion explains that the objects resist to change their state of rest or motion. It is also called law of Inertia.
- Inertia is the property of an object due to which it maintains its state of rest or motion.
- Newton's second law of motion states that a net force produces acceleration in the direction of force ($F = ma$).

- Newton's third law of motion states that for every action, there is an equal and opposite reaction.
- Centripetal force is required to move a body along a circular path.
- Centrifugal force is tendency of an object to move away from circular path. It is always opposite and equal to centrifugal force.
- Centrifuge equipments are helpful in many laboratory as well as daily life processes.
- The force that resists relative motion between two surfaces is called friction.
- Maximum static friction is called limiting friction. The static friction is always greater than kinetic friction.
- The Rolling friction is much lesser than the sliding friction due to smaller contact area.
- Safety devices are designed to decrease momentum of a body and provide extended time to remain safer.

CONCEPT MAP

Dynamics
Laws of motion
1st Law of motion
2nd Law of motion
3rd Law of motion
Vector quantity
is an example of
Force. F
N (SI unit)
Momentum
Ns (SI unit)
Which can produce
For example
For example
Causes an object to move in a straight line with increasing speed
Causes an object to slow down for the case of frictional force
which can be explained by
Newton's Second Law of motion
Rate of change of momentum
Law of conservation of momentum
given by
F= ma
where
F= resultant (net) force (in N)
m= mass (in kg)
a = acceleration (in ms)
Sliding friction
Rolling friction
Maximum friction
Minimum friction

End of Unit Questions

Section (A) Multiple Choice Questions (MCQs)

1. Newton's First law of motion is also known as law of
   - a) speed b) rest
   - c) inertia d) force
2. Quantity of matter contained in body is called______.
   - a) mass b) volume
   - c) area d) weight
3. Quantity of motion contained in a body is called
   - a) force b) inertia
   - c) momentum d) gravity
4. Law of conservation of momentum defines that the total momentum of a system of two bodies before and after collision__________.
   - a) remains constant
   - b) retains more momentum
   - c) losses some momentum
   - d) None of above is true
5. Weight of a body can be measured using a spring balance, it differs from place to place because of variation in _________.
   - a) acceleration b) gravitational pull
   - c) velocity d) size of spring balance
6. It is easier to push an empty shopping cart than a full one, because the filled cart has more mass than the empty one. This can be expressed by
   - a) $F > m$ b) $F < m$
   - c) $F \alpha 1/m$ d) $F \propto m$

7. Centrifugal force is always directed
   a) towards centre
   b) away from centre
   c) along the circular path
   d) all sides
8. Friction opposes motion between two bodies in contact because of
   a) charges on bodies
   b) weight of bodies
   c) roughness of surfaces
   d) None of above
9. Which statement is true for limiting frictional force.
   a) it is greater than rolling friction
   b) it is greater that sliding friction
   c) it is greater that kinetic friction
   d) all are true
10. A man pulls a crate of mass 25 kg across leveled ground with a horizontal force of 60 N.A constant force of friction of 20 N acts on the sledge. What is the acceleration of the sledge?
   a) $0.63\ ms^{-2}$ b) $1.6\ ms^{-2}$
   c) $2.4\ ms^{-2}$ d) $3.2\ ms^{-2}$

Section (B) Structured Questions

Momentum

1. a) Define momentum with SI unit?
   b) Find the moment of body of mass 6 kg moving with a velocity of $25\ ms^{-1}$.
   c) What will be the velocity if the momentum becomes 200Ns?

2. a) When a free falling object moves towards earth due to pull of earth on it. Does earth also move towards that object due to reaction? Explain.
   b) A body of mass 10 kg is moving with velocity of 10 ms^{-1}. A force acts for 5 seconds to reduce its velocity to 2 ms^{-1}. Find the momentum of body before and after application of the force on it.
3. a) Why a wire fence is designed in the helmet of batsman?
   b) How does it prevent from injuries?

Laws of motion

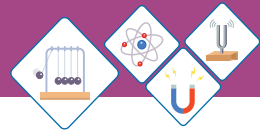
4. a) State the Newton's first law of motion. Give some common examples?
   b) Enlist some common observations that are caused by the property of inertia?
5. a) Define Newton's second law of motion.
   b) A force of 3400 N is applied on a body of mass is 850 kg, find the acceleration produced by the force?
   c) How much force should be applied on a body of mass 425kg to produce acceleration same as calculated in part b.
6. a) Show the relationship between applied force and the acceleration produced in the body?
   b) Find the mass of a body which is accelerated by applying a force of 200 N, that speeds up it to 36 ms^{-1}.
   c) What should be the acceleration of the same body if the applied force changes to 280N.
7. An empty car has 1200 kg mass. Its engine can produce acceleration of 4 ms^{-2}. If 300 kg load is added to mass by passengers and luggage. What acceleration the same engine will produce?

8. a) Enumerate at least three clear differences between mass and weight?
   b) The mass of an object is 60 kg, find its weight on (i) Earth (ii) Moon (iii) Mars assume the acceleration due to gravity on Earth = 9.8 ms^{-2} on Moon=1.6 ms^{-2} and on Mars= 3.7 ms^{-2}

Circular motion

9. a) Define the forces acting on an object in circular motion?
   b) Draw a figure showing the direction of centripetal force, centrifugal force and velocity of an object along a circular path.
   c) A car is running on a circular part of highway having about 1000m radius. The mass of car is 600kg and its velocity is 72 kmh. Find
      (i) Centripetal force exerted by the car.
      (ii) Centripetal acceleration of car.
   d) List down some purposeful uses of centrifuge that human are benefitting everyday.

Friction

10. a) What is force of friction? Explain with two examples from daily life.
    b) A block is placed on a wet slippery floor. The mass of block is 15 kg. When it is pulled through a string and spring balance, it shows force equal to 3 N. Find the coefficient of friction. ($F_s = \mu mg$)
11. a) How anti-lock braking system prevents the risk of sliding?
    b) Enlist any four uses of rolling friction in everyday life?

12. Explore the following phenomenon in relation with dynamics
    a) When an air filled balloon is released.
    b) Riding a bicycle needs continuous paddling.
    d) The biker ridding in the death well.
    e) You always feel a pullback whenever you pull on your school bag or some heavier object.

Unit - 4

TURNING EFFECT 0F FORCES

Modern day communication is possible through artificial satellites that move around the earth in geostationary orbits which is possible because of turning effects of forces. Driving of Vehicles, bicycle balancing while walking the tight rope requires the knowledge of the turning effects of force.

Students Learning Outcomes (SLOs)

After learning this unit students should be able to:

- Define like and unlike parallel forces
- State head to tail rule of vector addition of forces/vectors.
- Describe how a force is resolved into its perpendicular components
- Determine the magnitude and direction of a force from its perpendicular components.
- Define moment of force or torque as moment = force x perpendicular distance from pivot to the line of action of force.
- Explain the turning effect of force by relating it to everyday life.
- Illustrate by describing a practical application of moment of force in the working of bottle opener, spanner, door/windows handle etc.
- State the principle of moments
- Verify the princi1ple of moments by using a meter rod balanced on a wedge
- Define the center of mass and center of gravity of a body
- Determine the position of center of mass/gravity of regularly and irregularly shaped objects
- Define couple as a pair of forces tending to produce rotation.
- Prove that the couple has the same moments about all points
- Demonstrate the role of couple in the steering wheels and bicycle pedals
- Define equilibrium and classify its types by quoting examples from everyday life.
- State the two conditions for equilibrium of a body
- Solve problems on simple balanced systems when bodies are supported by one pivot only
- Describe the states of equilibrium and classify them with common examples.
- Explain effect of the position of the Centre of mass on the stability of simple objects.
- Demonstrate through a balancing toy, racing car etc., that the stability of an object can be improved by lowering the Centre of mass and increasing the base area of the objects.

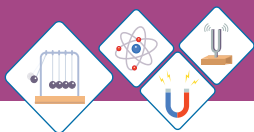



Fig 4.1

Fig 4.2

Do You Know!

- Force is a push or pull.
- It moves the objects.
- It stops the objects.
- It gives shape to the objects.
- It is a vector quantity. Therefore, it has a specific direction.
- It is measured in Newton (N).

Fig 4.3 (a)

Have you ever seen a driver changing wheel? Why does he use a long spanner? Sometimes he adds a piece of pipe to the spanner to increase the length as shown in figure 4.1. Have you visited a circus? Where you might have seen a man walking on a tight rope carrying a long beam. How that beam helps him to keep balance while walking on the tight rope. After learning this unit, you will be able to answer these questions and some other similar questions.

4.1 FORCES ON BODIES

Like and unlike parallel forces

Sometimes we find objects on which more than one forces are acting. In most cases, some or all of the forces are found acting in the same direction. For example, you might have seen many people pushing a car to move it Fig4.2. Why do all of them push it together in same direction? All of these forces are called like parallel forces because these are acting along same line. Like parallel forces can add up to a single resultant force, therefore, can be replaced by a single force.

The forces that act along the same direction are called like parallel forces.

Figure 4.3 (a) shows a ceiling fan suspended in a hook through supporting rod. The forces acting on it are; weight of the fan acting vertically downwards and tension in the supporting rod pulling it vertically upwards. These two forces are also parallel but opposite to each other and acting along the same line. Thus, these forces are called unlike parallel forces. These forces also add up to a single resultant force. But, when a pair of unlike forces do not act along the

Fig 4.3 (b)

same line as shown in figure 4.3(b), can be responsible for rotation of objects. Such unlike parallel forces cannot be replaced by a single resultant force and form a couple. A couple can only be balanced by an equal and opposite forces directed at the two different ends of the rod.

The forces that act along opposite directions are called unlike parallel forces.

Self Assessment Questions:

Q1: what is meant by like and unlike forces?

Q2: Differentiate like and unlike forces using examples.

4.2 ADDITION OF FORCES

Force is a vector quantity. It has both magnitude (size) and direction. In diagrams it is represented by a line segment with an arrow-head at one end to show its direction of action. Length of line segment gives the magnitude of the force on suitable scale. Wherever more than one force act on an object we need to add them to get a single resultant force:

single force that has the same effect as the combined effect of the forces to be added is called resultant force.

Ordinary arithmetic rules cannot be used to add the forces. Two different methods are used for the addition of forces (i.e., in general addition of vectors):

- Graphical Method
- Analytical Method

Graphical Method

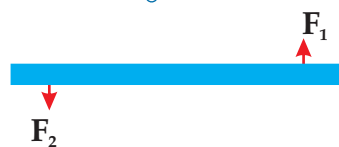
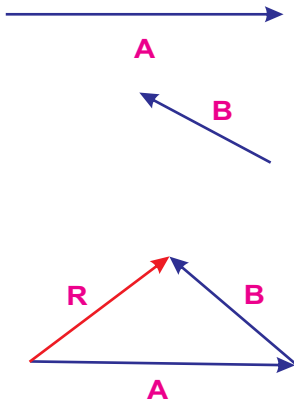
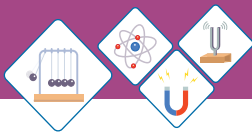
This method is used for addition of one-dimensional vector quantities. In this method head to tail rule of vector addition is used for the addition of forces.

Head to Tail Rule

Figure 4.4 shows head to tail rule of vector addition.

Fig 4.4

Step 1

Choose a suitable scale

Step 2

Draw all the force vectors according to scale. Vectors A and B in this case.

Step 3

Now take any vector as first vector and draw next vector in such a way that its tail coincides with head of the previous. If number of vectors is more than two then continue the process till last vector is reached.

Step 4

Use a straight line with arrow pointed towards last vector to join the tail of first vector with the head of last vector. This is the resultant vector.

Self Assessment Questions:

Q3: Define resultant of a forces.

Q4: which rule is used to find the resultant of more than two forces?

Worked Example 1

Find the resultant of three forces 15N along x-axis, 10N making an angle of 30^0 with x- axis and 10N along y-axis .

Solution

Step 1: Write the Known quantities and choose a suitable scale.

Here, F_1 = 15N along x-axis

F_2 = 10N 30^0 with x-axis

F_3 = 10N along Y-axis.

Scale 2N = 1cm.

Step 2: Draw the representative vectors for the forces F_1, F_2, F_3 according to the scale in the given directions as shown in figure 4.5.

Step 3: Take F_1 as first vector and draw F_2 and F_3 in such a way that the tail of next vector coincides with the head of the previous vector as shown in figure 4.5.

Step 4: Join the tail of the F_1 with the head of F_3 with a straight-line **F** with an arrow pointing towards F_3. According to head to tail rule, Force **F** represents the resultant force.

Step 5: Measure the length of **F** with a ruler and multiply it with $2Ncm^{-1}$ that is the magnitude of resultant. Measure the angle with protector that **F** makes with F_1. This gives the direction of resultant Force.

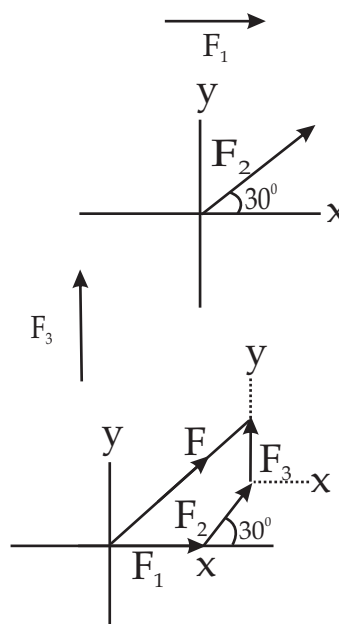
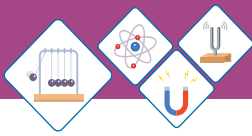
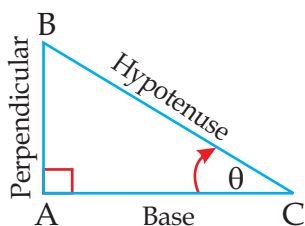



Fig 4.5

Trigonometric Ratios

The ratio between any two sides of a right-angled triangle are given specific names. There are six ratios in total out of which three are main ratios and other three are their reciprocals. Three main ratios mostly used in physics are sine, cosine and tangent. Consider a right-angled triangle ΔACB having angle θ at C.

$$\sin\theta = \frac{\text{Perpendicular}}{\text{Hypotenuse}} = \frac{AB}{BC}$$

$$\text{Cos}\,\theta = \frac{\text{Base}}{\text{Hypotenuse}} = \frac{AC}{BC}$$

$$\text{Tan}\,\theta = \frac{\text{Perpendicular}}{\text{Base}} = \frac{AB}{AC}$$

4.3 RESOLUTION OF FORCES

A force (vector) may be split into components usually perpendicular to each other; the components are called perpendicular components and the process is known as resolution of Vectors.

The process of splitting of a vector into mutually perpendicular components is called resolution of vectors.

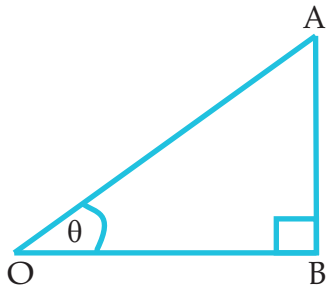



Fig 4.6

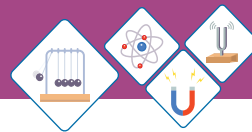
Figure 4.6 shows a force F represented by a line segment **OA** which makes an angle with x-axis. Draw a perpendicular AB on x-axis from A. The components **OB**= $\mathbf{F_x}$ and **BA** = $\mathbf{F_y}$ are perpendicular to each other. They are called the perpendicular components of **OA** = **F**. Therefore,

$$\mathbf{F = F_x + F_y} \quad ....(4.1)$$

The trigonometric ratios can be used to find the magnitudes Fx and Fy . In right angled triangle ΔOBA.

Table: 4.1
Trigonometric ratios

Ratio θ	0°	30°	45°	60°	90°
Sin θ	0	0.5	0.7070	0.8660	1
Cos θ	1	0.8660	0.7070	0.5	0
Tan θ	0	0.577	1	1.732	θ

$$\frac{F_x}{F} = \frac{OB}{OA} = \cos\theta$$

$$\mathbf{F_x = F\cos\theta} \quad ....(4.2)$$

Also,

$$\frac{F_y}{F} = \frac{BA}{OA} = \sin\theta$$

$$\mathbf{F_y = F\sin\theta} \quad ....(4.3)$$

Equations 4.2 and 4.3 give the perpendicular components respectively.

Worked Example 2

A man is pushing a wheelbarrow on a horizontal ground with a force of 300N making an angle of 60^o with ground (Fig 4.7). Find the horizontal and vertical components of the force.

Solution

Step 1: Write the known quantities and point out the quantities to be found.

$F = 200N$

$\theta = 60^o$ with horizontal.

$F_x = ?$

$F_y = ?$

Step 2: Write the formula and rearrange if necessary.

$F_x = F\cos\theta$

$F_y = F\sin\theta$

Step 3: Put the values in the formula and calculate.

$F_x = 300N \times \cos 60^o$

$= 300N \times 0.5$

$= 150\,N$

$F_y = F\sin\theta$

$F_y = 300N \times \sin 60^o$

$= 300N \times 0.8660$

$= 259.8N$

Therefor, horizontal and vertical components of pushing force are 150 N and 259.8N respectively.

Fig 4.7

Determination of Force from its Perpendicular Components

This is opposite to the process of resolution. If the perpendicular components of a force are known then the process of determining the force itself from the perpendicular components is called composition.

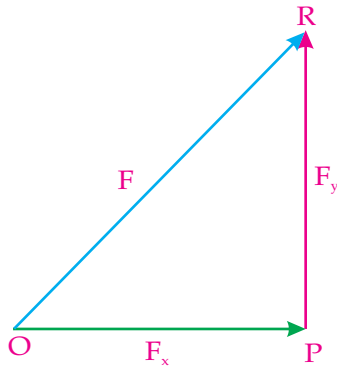
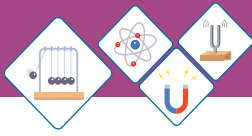



Fig 4.8

Suppose F_x and F_y are the perpendicular components of the force F and are represented by line segments **OP** and **PR** with arrowhead respectively as shown in figure 4.8.

Applying the head to tail rule:

$$\vec{OR} = \vec{OP} + \vec{PR}$$

Here **OR** represents the force **F** whose x and y – components are F_x and F_y respectively.

Thus,

$$F = F_x + F_y$$

In order to find the magnitude of **F** apply Pythagorean theorem to right angled triangle OPR i.e.,

$$(OR)^2 = (OP)^2 + (PR)^2 \quad \text{or} \quad F^2 = F_x^2 + F_y^2$$

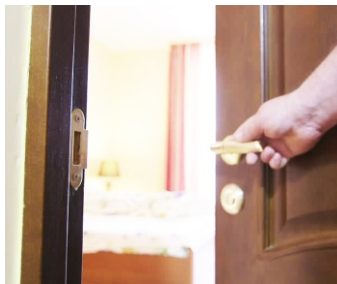
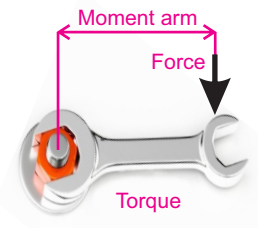
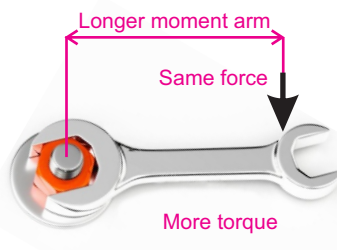
Therefore,

$$\mathbf{F} = \sqrt{F_x^2 + F_y^2} \quad \text{.................................(4.4)}$$

The direction of **F** with x-axis is given by

Fig 4.9

$$\tan\theta = \frac{PR}{OP} = \frac{F_y}{F_x}$$

$$\theta = \tan^{-1}\frac{F_y}{F_x} \quad \text{................................(4.5)}$$

Self Assessment Questions:

Q5: What is meant by resolution of forces?

Q6: How the direction of a vector is obtained from its components?

4.4 TORQUE OR MOMENT OF FORCE

A door handle is fixed at the outer edge of the door so that it opens and closes easily (Figure 4.9). A larger force would be required if handle were fixed near the inner edge close to the hinge. Similarly, it is easier to tighten or loosen a nut with a long spanner as compared to short one (fig 4.10).

Fig 4.10

The **turning effect of force** is called **moment of force** or **Torque**.

It depends upon:

- The magnitude of force.
- The perpendicular distance of the point of application of force from the Pivot or fulcrum.

Moment of force about a point = Force × Perpendicular distance from point

or $\tau = F \times d$.................(4.6)

depending on their direction, SI unit of the torque or moment of force is newton -metre (Nm).

Moments are described as **clockwise** or **anticlockwise.**

Weblinks

Web links for moment of force.

- http://www.saburchill.com/physics/chapters/0018.html
- http://www.walter.fendt.de/ph11e/lever.htm
- http://www.lovephysics.com/tur

Worked Example 3

A car driver tightens the nut of wheel using 20 cm long spanner by exerting a force of 300N. Find the torque.

Solution

Step 1: Write the known quantities and point out the quantity to be found.

$F = 300N$

$L = 20\,cm = 0.20m$

$\tau = ?$

Step 2: Write the formula and rearrange if necessary.

$\tau = F \times L$

Step 3: Put the values in formula and calculate

$\tau = 300N \times 0.20m = 60Nm$

Thus, torque of 60Nm is used to tighten the nut.

Self Assessment Questions:

Q7: List the factors on which moment of force depends.

Q8: What will be moment of force? When 500N force is applied on a 40cm long spanner to tighten a nut.

4.5 PRINCIPLE OF MOMENT

Fig 4.11

Two children playing on the see-saw (Fig.4.11). Fatima is sitting on right side and Faheem on the left side of the pivot.

When the clockwise turning effect of Fatima is equal to the anticlockwise turning effect of Faheem, then see-saw balances. In this case they cannot swing.

When the sum of all the clockwise moments on a body is balanced by the sum of all the anticlockwise moments, this is known as principle of moments. According to the principle of moments:

The sum of the clockwise moments about a point is equal to the sum of the anticlockwise moments about that point.

Self Assessment Questions:

Q9: How is the see- saw balanced?

Q10: Give three examples in which principle of moment is observed.

Worked Example 4

Consider a meter rod supported at mid-point O as shown in figure 4.12. The block of 20N is suspended at point A 30cm from O. Find the weight of the block that balances it at point B, 20cm from O.

Solution

Step 1: write known quantities and point out unknown quantities.

$W_1 = 20N$

Moment arm of W_1 = OA = 30cm =0.30m

Moment arm of W_2 = OB = 20cm

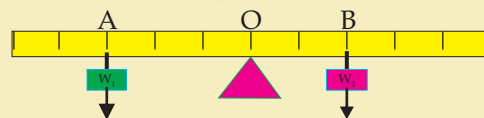
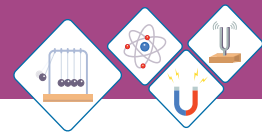



Fig 4.12

Step 2: write formula and re arrange if necessary.

Clockwise moments = anticlockwise moments

$W_1 \times OA = W_2 \times OB$

$$W_2 = \frac{W_1 \times OA}{OB}$$

Step 3: Put the values and calculate.

$$W_2 = \frac{20N \times 0.3m}{0.20m}$$

$= 30N$

Thus, the weight of the block suspended at point B is 30N.

4.6 CENTRE OF MASS OR CENTRE OF GRAVITY

A body behaves as if its whole mass is concentrated at one point, called its **centre of mass** or **centre of gravity**, even though earth attracts every part of it.

Fig 4.13 (a)

Fig 4.13 (b)

The centre of mass of a uniform metre rod is at its centre and when supported at that point, it can be balanced as shown in figure 4.13a. If it is supported at any other point it topples because the moment of its weight **W** about the point of support is not zero as shown in figure 4.13 b.

Fig 4.14 (a)

Center of Gravity of Some Regular Shaped objects

The Center of gravity of regular shaped uniform objects is their geometrical Center.

- The Center of gravity of uniform rod is its mid-point as shown in figure 4.14 a
- The Center of gravity of uniform square or a rectangular sheet is the point of intersection of its diagonals as shown in figure 4.14b and 4.14c.
- The Center of gravity of solid or hollow sphere is the Center of the sphere as shown in figure 4.14d.

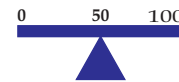
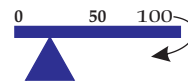
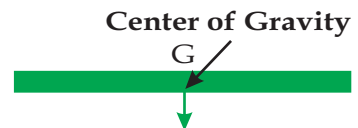
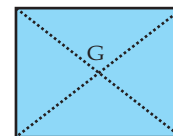



Fig 4.14 (b)

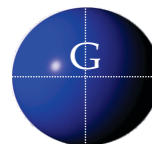



Fig 4.14 (c)

Fig 4.14 (d)

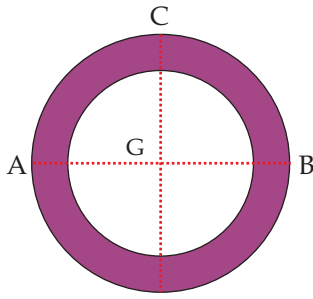
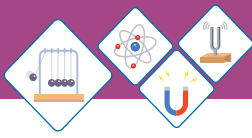



Fig 4.14 (e)

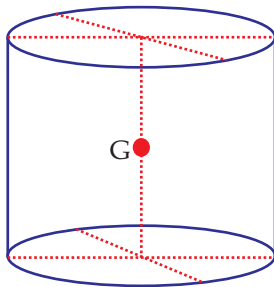



Fig 4.14 (f)

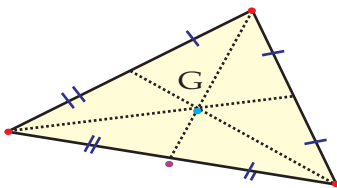



Fig 4.14 (g)

- The Center of gravity of uniform circular ring is the Center of ring as shown in figure 4.14e.
- The Center of gravity of uniform circular disc is its Center as shown in figure 4.14d
- The Center of gravity of a uniform solid or hollow cylinder is the mid-point on its axis as shown in figure 4.14f.
- The Center of gravity of a uniform triangular sheet is the point of intersection of its medians as shown in figure 4.14g.

Center of Gravity of Irregular Shaped Thin Lamina

Step 1: Make three small holes near the edges of the lamina farther apart from each other.
Step 2: Suspend the lamina freely from one whole on retort stand through a pin as shown in figure 4.15a.
Step 3: Hang a plumb line or weight from the pin in front of the lamina as shown in figure 4.15b.
Step 4: When the plumb line is steady, trace the line on the lamina.
Step 5: Repeat steps 2 to 4 for second and third hole. The point of intersection of three lines is the position of Center of gravity.

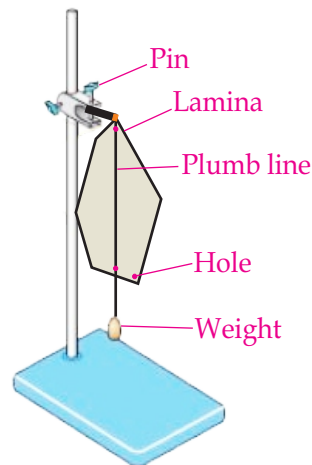
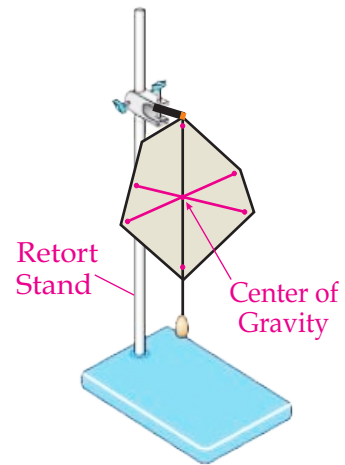



Fig 4.15 (a) Fig 4.15 (b)

4.7 COUPLE

When a boy riding the bicycle pushes the pedals, he exerts forces that produces a torque as shown in figure 4.16. This torque turns the toothed wheel making the rear wheel to rotate. These forces act in opposite direction and form a **couple**.

Fig 4.16

Two unlike parallel forces of the same magnitude but not acting along the same line form a couple.

Figure 4.17 shows the forces required to turn steering wheel of a car. The two equal and opposite forces balance, so the wheel will not move up, down or sideways. However, the wheel is not in equilibrium.

The pair forces will cause it to rotate.

A pair of forces like that in figure 4.17 is called couple. A couple has turning effect but does not cause an object to accelerate. To form a couple, two forces must be:

- Equal in magnitude
- Parallel, but opposite in direction
- Separated by a distanced.

Fig 4.17

The turning effect or moment of a couple is known as its torque. We can calculate the **torque** of the couple in figure 4.17 by adding the moments of each force about the Center O of the wheel:

Torque of couple $= (F \times OP) + (F \times OQ)$

$= F \times (OP + OQ)$

$= \mathbf{F} \times \mathbf{d}$ ....(4.6)

Torque of couple = one of the forces × perpendicular distance between the forces.

Self Assessment Questions:

Q11: Write three necessary conditions for two forces to form a couple.

Q12: If two forces 5N each form a couple and the moment arm is 0.5m .Then what will be torque of the couple?

4.8 EQUILIBRIUM

When a body does not possess any acceleration neither linear nor angular it is said to be in equilibrium. For example, a book lying on table in rest, a paratrooper moving downwards with terminal velocity, a chair lift hanging on supporting ropes (Fig4.18).

There are two types of equilibrium.

- **Static Equilibrium**
- **Dynamic Equilibrium**

Fig 4.18
A chair lift hanging on supporting ropes.

Static Equilibrium

A body at rest is said to be in static equilibrium.

A wall hanging (fig 4.19), buildings, bridges or any object lying in rest on the ground are some examples of static equilibrium.

Fig 4.19
A wall hanging is in equilibrium.

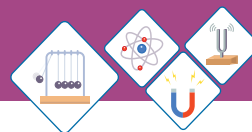
Dynamic Equilibrium

A moving object that does not possess any acceleration neither linear nor angular is said to be in dynamic equilibrium.

For example, uniform downward motion of steel ball through viscous liquid and jumping of the paratrooper from the Helicopter (Fig. 4.20).

Fig 4.20
A paratrooper jumping from helicopter

Conditions for Equilibrium

A body must satisfy certain conditions to be in equilibrium. There are two conditions for equilibrium:

First Condition for Equilibrium

According to this condition for equilibrium sum of the all forces acting on a body must be equal to zero. Suppose n number of forces F_1, F_2, F_3, ………, F_n are acting on a body then according to first condition of equilibrium:

$F_1+F_2+F_3+.................+F_n=0$ or

$\mathbf{\Sigma F=0}$ ....(4.7)

The symbol Σ (a Greek Letter Sigma) is used for summation. Equation 4.7 is known as first condition for equilibrium.

In terms of x and y components of the forces acting on the body first condition for the equilibrium can be expressed as:

$F_{1x}+F_{2x}+F_{3x}+...............+F_{nx}=0$ and

$F_{1y}+F_{2y}+F_{3y}+.................+F_{ny}=0$ or

$\mathbf{\Sigma F_x=0}$ ....(4.8)

$\mathbf{\Sigma F_y=0}$ ....(4.9)

A basket of apples resting on the table or a clock hanging on the wall are at rest and hence satisfy first condition for equilibrium. A paratrooper moving down with terminal velocity also satisfies first condition for equilibrium.

Weblinks

Teacher may encourage learners to visit the conditions of equilibrium on internet at

http://www.ul.ie/-gaughrn/Gildea/page4.html

Second Condition For Equilibrium

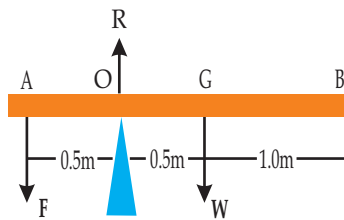
First condition for the equilibrium does not confirm that a body is in equilibrium because a body may have angular acceleration even though first condition is satisfied. For example, consider two forces F_1 and F_2 are acting on a body as shown in figure 4.21a. The two forces are equal and opposite to each other. The line of action of two forces is same, thus resultant will be zero. The first condition for equilibrium is satisfied,

Fig 4.21 (a)

Fig 4.21 (b)

hence we may think that the body is in equilibrium. However, if we change the position of the forces as shown in figure4.21b. Now the body is not in equilibrium even though first condition for equilibrium is still satisfied. This shows that there must be an additional condition for equilibrium to be satisfied for a body to be in equilibrium. This is called second condition for equilibrium.

Sum of all clockwise and anticlockwise torques acting on a body is zero. Mathematically,

$\Sigma\tau = 0$ ....(4.10)

Worked Example 5

A uniform rod of length 2.0m is placed on a wedge at 0.5m from its one end (Fig4.22). A force of 150N is applied at one of its ends near the wedge to keep it horizontal. Find the weight of the rod and the reaction of the wedge.

Fig 4.22

Solution

Step 1: Write the known quantities and point out unknown.

$F = 150N$

$OA = 0.5\,m$

$AG = BG = 1.0m$

$OG = AG - AO = 1.0m - 0.5m$

$= 0.5m$

$W = ?$

$R = ?$

Step 2: Write formula and substitute values.

For W applying second condition of equilibrium, taking torques about O.

$\Sigma\tau = 0$

$F \times AO + R \times 0 + W \times OG = 0$

$150 \times 0.5 - W \times 0.5 = 0$ or

$$W \times 0.5m = 150 \times 0.5m$$

$$W = \frac{150N \times 0.5m}{0.5m}$$

$$W = 150N$$

For R applying first condition of equilibrium

$$\Sigma F_y = 0$$

$$R - F - w = 0$$

$$R - 150N - 150N = 0 \text{ or}$$

$$R = 300N$$

Therefore, weight of the rod is 150N and reaction of the wedge is 300N.

Weblinks

Encourage student to visit the below link for states os equilibrium.

http://www.cityco llegiate.com/statics Xlb.htm

States of Equilibrium

There are three states of equilibrium:

- Stable equilibrium
- Unstable equilibrium and
- Neutral equilibrium

A body may be in one of the above states of equilibrium.

Stable Equilibrium

Suppose a box is lying on the table. It is in equilibrium. Tilt the box slightly about its one edge as shown in figure4.23. on releasing it returns back to its original position. This state of body is known as stable equilibrium.

(a) A box lying on the table.
(b) The box returns to its previous position when left free after a slight tilt..

Fig 4.23

A body is in stable equilibrium if when slightly displaced and then released it returns to its previous position.

- A body is in stable equilibrium when:
- Its Centre of gravity is at lowest position
- When it is tilted its Centre of gravity rises
- It returns back to stable state by lowering its Centre of gravity

Fig 4.24

Note: A body remains in stable state of equilibrium as long as its Centre of gravity acts through the base of the body.

Unstable Equilibrium

Take a paper cone and try to keep it in vertical position on its vertex as shown in figure 4.24. it topples down on releasing. This state of body is known as unstable equilibrium.

A body is said to be in unstable equilibrium when slightly tilted does not return back to its previous position.

A body is in unstable equilibrium when:

- Its Centre of gravity is at highest position
- When it is tilted its Centre of gravity is lowered
- Its previous position cannot be restored by raising its

Fig 4.25

Neutral Equilibrium

Consider a ball placed on a horizontal surface as shown in figure 4.25a. It is in equilibrium. When it is displaced from its previous position it remains in its new position still in equilibrium as shown in figure 4.25b. This is called neutral equilibrium.

A body is said to be in neutral equilibrium when displaced from previous position remains in equilibrium in new position.

A body said to be in neutral equilibrium when:

- Its Center of gravity always remains above the point of contact.
- When it is displaced from its previous position its Centre of gravity remains at same height.
- All the new states in which body is moved are the stable states.

Do You Know!

A man walking on tight rope carries a long beam which helps him to maintain balance by lowering his Center of mass.

Self Assessment Questions:

Q13: List three states of equilibrium.

Q14: Why a body in unstable equilibrium does not return back to it original position when given a small tilt?

4.9 STABILITY

In most situation we are interested in maintaining stable equilibrium, or balance for example design of structures, racing cars and in working with human body. Consider a refrigerator (Fig. 4.26a) if it is tilted slightly (fig.4.26b) it will return back to its original position due to torque on it. But if it is tilted more (Fig.4.26c), it will fall down. The critical point is reached when the centre of gravity shifts from one side of the pivot point to the other. When the centre of gravity is on the one side of the pivot point, the torque pulls the refrigerator back onto its original base of support (Fig. 4.26b). If the refrigerator is tilted further, the centre of gravity crosses onto the other side of the pivot point and the torque causes the refrigerator to topple (Fig.4.26c). In general,

Fig 4.26

A body whose center of gravity is above its base of support will be stable if a vertical line projected downward from the center of gravity falls within base of support.

Fig 4.27

A sewing needle fixed in a cork is shown in figure 4.27. The forks are hanged on the cork to balance it on the tip of the needle. The forks lower the centre of mass of the system. If it is disturbed will return back to original position. A perched parrot is shown in figure 4.28. it is made heavy at tail which lowers its centre of gravity. it can keep itself upright when tilted. In

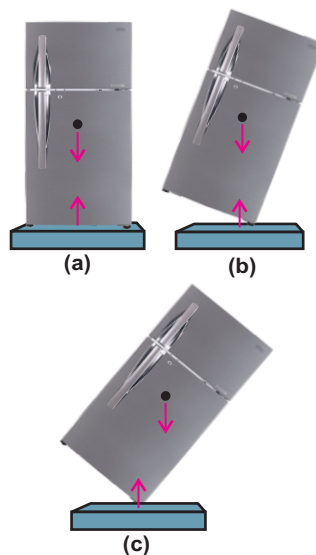
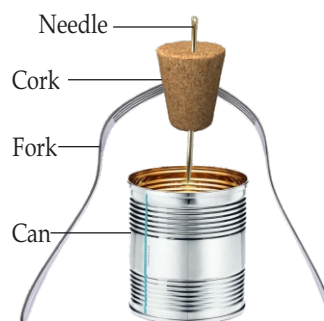
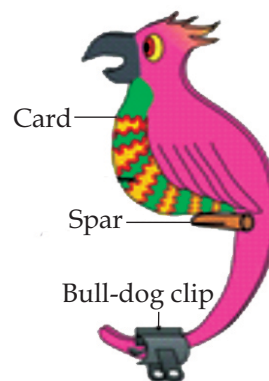
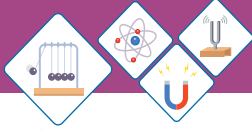



Fig 4.28

Do You Know!

The sports cars are made heavy at bottom which lowers the Center of mass and hence increases the stability.

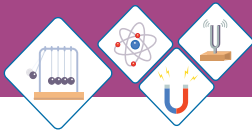
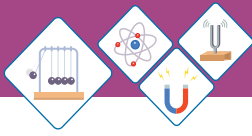
general, larger the base and lower the centre of gravity, more stable the body will be.

Self Assessment Questions:

Q15: Why racing cars are made heavy at bottom?

Q16: Why the base area of Bunsen burner is made large?

SUMMARY

- Lines of action of parallel forces are parallel to each other.
- Parallel forces with same direction are called like parallel forces.
- Parallel forces with opposite directions are called unlike parallel forces.
- The sum of the two or more forces is called the resultant of forces.
- The graphical method for addition of forces is called head to tail rule.
- Splitting of a force into two perpendicular components is called resolution of force. The components are $F_x = F\cos\theta$, $F_y = F\sin\theta$
- Perpendicular components can be used to determine a force as
- $F = \sqrt{F_x^2 + F_y^2}$ $\quad \theta = \tan^{-1}\dfrac{F_y}{F_x}$
- Turning effect of force is called moment of force or torque.
- The product of the force and the moment arm of the force is equal to the torque.
- The principle of moment states that a body is in equilibrium, if sum of the clockwise moments acting on a body is equal to the sum of the anticlockwise moments acting on the body.
- The Center of mass or Center of gravity is a point where whole weight of the body acts vertically downward.
- Two equal and opposite forces acting along different lines of action form a couple.
- First condition for equilibrium is satisfied if net force acting on a body is zero.
- Second condition for equilibrium is satisfied if sum of clockwise torques acting on a body is equal to the

sum of the anticlockwise torques.

- A body is said to be in stable equilibrium if it returns back to previous position after slight tilt.
- A body is said to be in unstable equilibrium if it does not return to previous position on releasing after a slight tilt.
- A body is to be in neutral equilibrium if it does not return back to previous position but remains in equilibrium at new position after disturbance.

Turning effect of a force

known as

Moment of a force

is defined as

Moment = F×d

Nm (SI unit)

F= force
d= perpendicular distance from the force to the pivot

which is of two types

Clockwise moment

Anticlockwise moment

which is equal

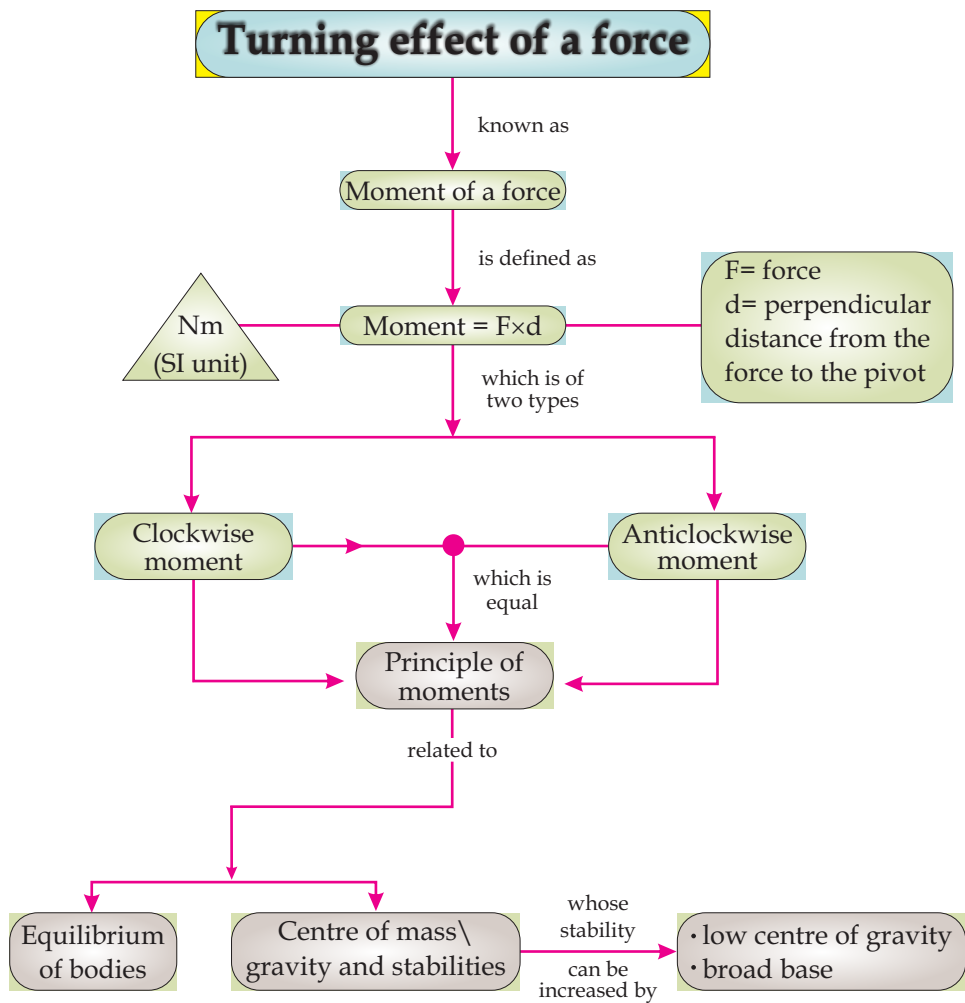
Principle of moments

related to

Equilibrium of bodies

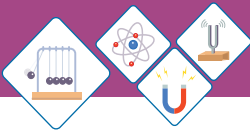
Centre of mass\ gravity and stabilities

whose stability can be increased by

- low centre of gravity
- broad base

End of Unit Questions

Section (A) Multiple Choice Questions (MCQs)

1. A pair of unlike parallel forces having different lines force produce----------.
   a) equilibrium b) torque
   c) a couple d) unstable equilibrium
2. Head to tail rule can be used to add------------ forces.
   a) two b) three
   c) five d) any number of
3. A force of 15 N makes an angle of 60° with horizontal. Its vertical component will be:
   a) 15N b) 10N
   c) 13N d) 7 N
4. A body is in equilibrium when it has
   a) uniform speed b) uniform acceleration
   c) both a and b d) zero acceleration
5. A body is in stable equilibrium after slight tilt if its Centre of gravity
   a) remains above the point of contact
   b) remains on one side of point of contact
   c) passes over the point of contact
   d) is at lowest position
6. A body is in unstable equilibrium after slight tilt if its center of gravity
   a) remains on one side of the point of contact
   b) remains above the point of contact
   c) passes over the point of contact
   d) is positioned at its bottom

7. A body is in neutral equilibrium when its Centre of gravity
   a) Is at the lowest position
   b) Remains at same height
   c) Is at highest position
   d) Is at its base
8. Bunsen burner is made stable by
   a) Increasing its length
   b) Increasing its mass
   c) Decreasing its base area
   d) Increasing its base area
9. A tight rope walker carries a long pole to
   a) Increase his weight
   b) Raise his Centre of gravity
   c) Lower his Centre of gravity
   d) Keep his Centre of gravity in fixed position
10. Stability of a racing car is increased by
   a) Increasing its height
   b) Raising its Centre of gravity
   c) Decreasing its width
   d) Lowering its Centre of gravity

Section (B) Structured Questions

Forces on bodies

1. a) Define like and unlike forces.
   b) A pair of like parallel forces 15N each are acting on a body. Find their resultant.
   c) Two unlike parallel forces 10 N each acting along same line. Find their resultant.

Addition of forces

2. a) Describe the head to tail rule of vector addition of forces.
   b) Three forces 12 N along x-axis, 8 N making an angle of 45° with x-axis and 8 N along y-axis.
   i) Find their resultant
   ii) Find the direction of resultant

Resolution of forces

3. a) How a force can be resolved into its perpendicular components?
   b) A gardener is driving a lawnmower with a force of 80 N that makes an angle of 40° with the ground.
   i) Find its horizontal component
   ii) Find its vertical component
4. a) How can you determine a force from its rectangular components?
   b) Horizontal and vertical components of a force are 4 N and 3 N respectively. Find
   i) Resultant force
   ii) Direction of resultant

Moment of force

5. a) What do you mean by moment of force? [3]
   b) A spanner of 0.3 m length can produce a torque of 300Nm.
      i) determine the force applied on it [2]
      ii) What should be the length of the spanner if torque is to be increased to 500Nm with same applied force [3]

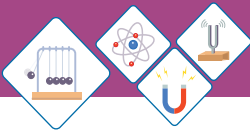
Principle of moments

6. a) State the principle of moment
   b) A uniform meter rule is supported at its center is balanced by two forces 12 N and 20 N
      i) if 20 N force is placed at a distance of 3m from pivot find the position of 12 N force on the other side of pivot
      ii) if the 20N force is moved to 4cm from pivot then find force to replace 12N force.

Center of mass

7. a) Define Center of mass or Center of gravity.
   b) How will you determine the Center of mass or Center of gravity?

Couple

8. a) Define couple as a pair of forces tending to produce torque
   b) A mechanic uses a double arm spanner to turn a nut. He applies a force of 15 N at each end of the spanner and produces a torque of 60 Nm. What is the length of the moment arm of the couple?

c) If he wants to produce a torque of 80Nm with same spanner then how much force he should apply?

Equilibrium

9. a) state two conditions necessary for an object to be in equilibrium.

   b) A uniform metre rule is balanced at the 30 cm mark when a load of 0.80 N is hung at the zero mark.

   i) At what point on the rule is the Centre of gravity of the rule?

   ii) calculate the weight of the rule

Unit - 5

FORCES AND MATTER

Students Learning Outcomes (SLOs)

After learning this unit students should be able to:

- Use forces to change the shape and size of the body
- Carry out experiment to produce extension against load graph
- Interpret extension against load graph
- Define Hooke's law
- Calculate extension in spring and spring constant using formula $F = kx$
- Define and explain pressure
- Understand the factors that affects the pressure
- Calculate the pressure using formula $p = F/A$
- Understand hydraulic machines

You can not see force, but you can see what it does. You have learnt that how force can change the motion of objects. Force can make the object speed up, slow down, start moving, stop or change direction. But force has another effect. A force can also change the shape or size of an object.

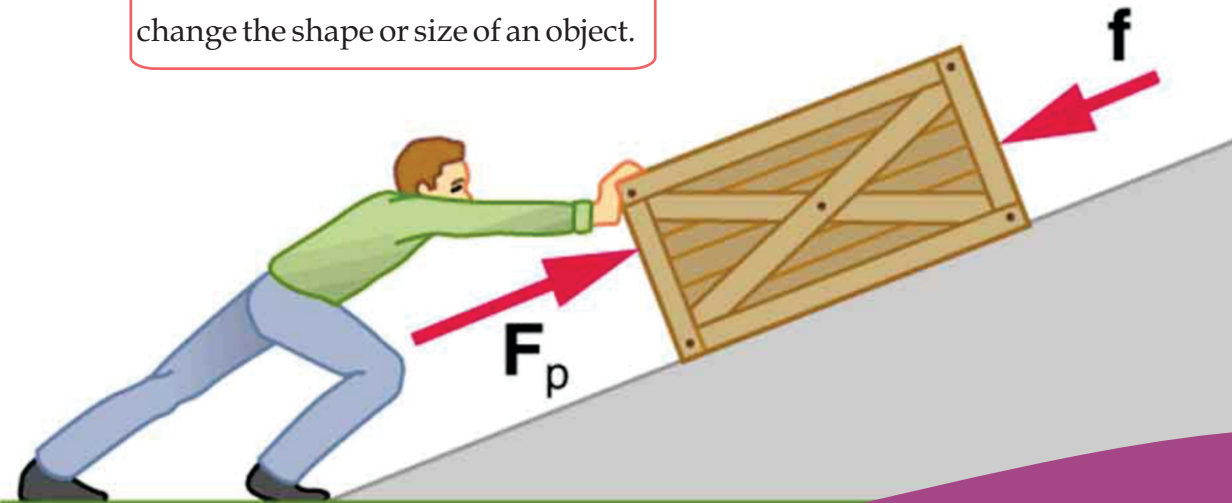



Fig 5.1 (a)

- Force is needed to move a car.
- Force causes the spring to stretch.
- We need force to move some luggage.
- If you bend your plastic ruler you will change its shape.

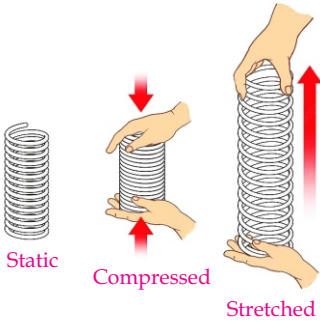



Fig 5.1 (b)

Force applied by hands on the dough changes its shape; Fig 5.1 (a). A spring can be stretched or compressed by applying force; Fig 5.1 (b).

Notice that, what effect a force has, depends on the materials involved. Soft materials, such as rubber can bend and flex very easily. A spring comes back to its original shape when you remove the force. Materials like this are called elastic.

When force is exerted on area, this is known as pressure; Fig 5.1 (c).

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

Fig 5.1 (c)

As you have already studied that hydraulic machines also work on principals of fluid pressure. Hydraulic breaks are used almost in all vehicles. They cause a relatively small force from the driver's foot to be multiplied to produce a greater force, which acts equally on all four brake pads.

Force

Force can be defined as

A push or a pull that changes or tends to change the state of rest or uniform motion of an object or changes the direction or shape of an object.

5.1 FORCES ACTING ON SOLIDS

Solids have definite shapes and sizes, however it is possible to change their shapes and sizes by applying external forces. When the external force is removed, the object tends to return to its original shape and size. This behavior is called elastic behaviour. Solids can be stretched, squashed, bend or twisted Fig 5.2 (a, b). These figures show the different ways in which elastic behavior of solid objects can be demonstrated. A sufficiently large force will permanently deform or break an object Fig 5.2 (c).

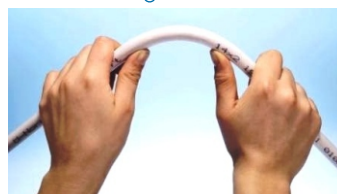



Fig 5.2(a)
A Force can bend an object

Fig 5.2(b)
A Force can twist an object

Fig 5.2(c)
A force can deform an object

5.2 STRETCHING SPRINGS

As springs are designed to stretch a long way when force is applied, therefore it is easy to measure changes in their lengths.

To explain how solids are deformed? let us perform an experiment with the spring.

Consider a spring hung from a rigid support, so that its top end is fixed; Fig 5.3 (a). Weights are hung on other end of the spring. These are called load. As load is increased, the spring is stretched and its length increases.

When the load is removed, the spring returns to its original length. This is called elastic change. When the load is increased in regular steps the length of the spring also increases simultaneously Fig 5.3 (b). If the load is increased greatly, the spring will change its shape permanently.

Fig 5.3 (a)
unstretched spring

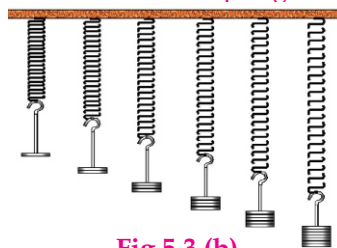
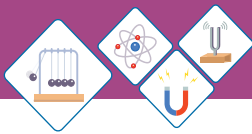



Fig 5.3 (b)
Stretching of spring

Extension of spring

The length of spring increases as the force (load) increases; Fig 5.3 (b). This increase in length of spring is

Do You Know!

When you pull on the band, it stretches but doesn't break. The resistance you feel when you pull on it is elastic force. The farther you stretch the band, the greater the elastic force. After you stop pulling the band, it returns to its original shape.

known as extension. Hence

Length of stretched spring = Original length + Extension

Let's carry out an experiment to stretch a spring of original length 20cm. Table 5.1 shows recorded result of this experiment. The first column shows the increase in load in regular steps. Second column shows the increase in length of stretched spring. Third column shows the value of extension, due to change in length in each step.

Table 5.1 for load and extension

Load (N)	Length (cm)	Extension (cm)
0.0	20	0.0
2.0	21	1.0
4.0	22	2.0
6.0	23	3.0
8.0	24	4.0
10	25	5.0
12	26	6.0
14	28	8.0
16	30	10

Table 5.1 shows how a spring stretches as the load on it increases. Dependance of extension on load, shown in Fig 5.3 (c).

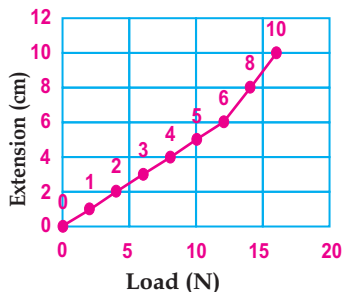



Fig 5.3 (c)
Graph between load and extension

you can see that the graph has two parts.

- At first, the graph slopes up steadily. This shows that the extension increases in equal steps as the load increases. This behaviour can also be observed in table 5.1
- Then the graph bends. This happens when the load is greater enough to damage the spring permanently. As a result the spring will not return to its original length.

Self Assessment Questions:

Q1: An elastic spring is 70cm long. When it is stretched by hanging some load its length increases to 100cm. Calculate its extension?

Q2: Table 5.2 shows the results of an activity to stretch an elastic spring. Complete the table and draw a graph to represent this data.

Table 5.2: for load and extension

Load (N)	Length (cm)	Extension (cm)
0.0	30	0.0
1.0	32	
2.0	34	
3.0	36	
4.0	38	
5.0	40	
6.0	41.5	
7.0	42	
8.0	43	

Quick Lab

Investigating the spring:

1. Hang some weights(load) to stretch the spring.
2. Note down the extension in the spring.
3. Increase the weight(load) gradually of equal magnitudes.
4. Note down corresponding reading of extension.
5. Make a table of load and extension.
6. Plot a graph between load and extension to obtain the behavior (pattern) of the spring.

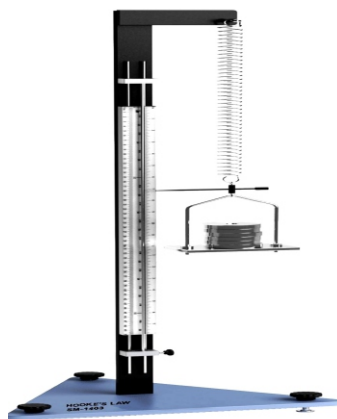



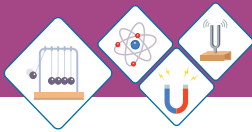
Fig 5.4
Extension in the spring depends upon the load.

5.3 Hooke's law

Robert Hooke, an English scientist first described the mathematical pattern of stretching a spring. He observed the dependence of displacement or size of the deformation upon the deforming force or load. Hooke's law states that:

Within elastic limit, the displacement produced in the spring is directly proportional to the force applied.

ELASTICITY

Elasticity is the property of a body to regain its original shape and size when deforming forces are removed.

Do You Know!

Material	Young's Modulus (in GPa)
Brass	91
Copper	120
Mild steel	210
Plastic	2
Rubber	0.02

Where 1GPa = 10^9Pa

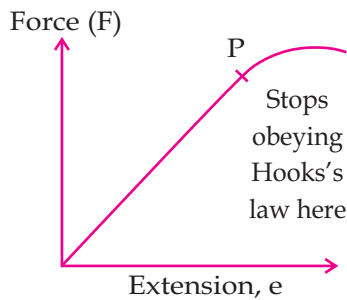



Fig 5.5
Graph between force and extension.

Do You Know!

Why springs?
Robert Hooke a scientist and inventor was interested in springs for two reasons.

1. Spring are useful in making balances. Hooke wanted to make a very sensitive and accurate weight machine or balance.
2. He also realised that a spiral spring could be used to control a clock or wrist watch.

Mathematically if 'F' is the applied force and 'x' is the displacement (extension) in the spring then the equation for Hooke's law may be written as:

$$F \propto x$$

or $$F = kx \quad \text{.......................(5.1)}$$

where k is spring constant (stiffness of spring).

Hooke's law is applicable to all kinds of deformation and all types of matter i.e., solids, liquids or gases within certain limit. This limit tells the maximum force or stress that can be safely applied on a body without causing permanent deformation in its length, volume or shape. In other words, it is a limit within which a body recovers its original length, volume or shape after the deforming force is removed. Beyond this limit spring deforms permanently; Fig 5.5.

Worked Example 1

A spring has spring constant $k = 30\ Nm^{-1}$. What load is required to produce an extension of 4 m?

Solution

Step:1 Write down known quantities and the quantities to be found.

$k = 30\ Nm^{-1}$

$x = 4\ m$

$F = ??$

Step:2 Write down formula and rearrange if necessary

$F = kx$

Step:3 Put the values in formula and calculate

$F = 30Nm^{-1} \times 4m$

$F = 120N$

Hence 120N load is required to stretch the spring by 4m.

Self Assessment Questions:

Q3: How much force is needed to pull a spring to a distance of 30cm, the spring constant is 15 Nm^{-1}?

Q4: Write two properties of spring.

5.4 Pressure

Press a pencil from its ends between the palms; Fig 5.6.

Fig 5.6

The palm pressing the tip feels much more pain than the palm pressing its blunt end. We can push a drawing pin into a wooden board by pressing it by our thumb; Fig 5.7. It is because the force we apply on the drawing pin is confined just at a very small area under its sharp tip. A drawing pin with a blunt tip would be very difficult to push into the board due to the large area of its tip.

Fig 5.7
A drawing pin with a sharp tip enters easily when pressed.

In these examples, we find that the effectiveness of a small force is increased if the effective area of the force is reduced.

The area of the tip of pencil or that of the nail is very small and hence increases the effectiveness of the force. The quantity that depends upon the force and increases with decrease in the area on which force is acting is called pressure. Thus, pressure is defined as

The force acting normally per unit area on the surface of a body is called pressure.

Thus,

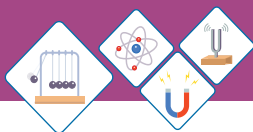
$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

$$P = \frac{F}{A} \quad \text{.......................(5.2)}$$

Do You Know!

The pressure exerted by the air molecule at sea level is measured in atmosphere; where:
1 atmosphere = 1.013×10^5 Pascal
∴ 1 atm = 1.013×10^5 Pa

How to calculate pressure

If F is the magnitude of a force exerted perpendicular to a given surface of area A, then the pressure P equals to the force divided by the area:

Do You Know!

Why an acrobat does not hurt when he lied down on the bed of nails?

There is no miracle in this trick. We know that pressure is defined as force per unit area. If you step up on a nail, the entire body weight exerts more pressure because the area of nail tip is very small. In case of bed nails, the pressure exerted by weight of body is distributed on the hundreds or thousands of nails lying close to each other. Thus, net pressure on a nail is very small. Hence, an acrobat does not hurt when he lied down on the bed of nails.

An acrobat laying on bed of nails

$$P = F/A$$

As the force is measured in newtons (N) and area in square meters (m^2). Therefore in SI system unit of pressure is newton per square meter (Nm^{-2}). It is also known as Pascal (Pa):

$$1\ Pa = 1\ Nm^{-2}$$

High pressure, low pressure

The pressure under the studs on the soles of football shoes is high enough to sink into the ground, which gives extra grip. Ice skates have blades in the part that is in contact with ice. Therefore the skater's weight is concentrated on a small area. The effect of this high pressure melts ice just below the blades. This gives the thin film of water, which provide lubrication for the skate to skim over the ice. As the skate moves on, the water re-freezes. On very cold days, the pressure may not be enough to melt the ice, and skating is impossible. An elephant has broad soles to reduce the pressure exerted on the ground. Wide shoulder pads of school bag reduce pressure on the student's shoulder.

Self Assessment Questions:

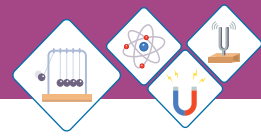
Use the idea of pressure to explain the following.

Q5: Sharks and crocodiles have sharp teeth.

Q6: Camels have wide, flated feet.

Q7: If you walk on wooden floor wearing shoes with very narrow heels, you will damage the floor.

Pressure in fluids

A fluid is a collection of molecules that are randomly arranged and held together by weak

cohesive forces and by forces exerted by the walls of a container. Both liquids and gases are fluids. The pressure exerted by fluids is known as fluid pressure. It acts in all directions. This is because the molecules of fluids move around in all directions, causing pressure on every surface they collide with. A swimmer in swimming pool experience the pressure by water which pushes the swimmer from all sides Fig 5.8. The arrows represent the direction and magnitude of the forces exerted at various points on the swimmer. Note that the net underneath force is larger due to greater depth, giving a net upward or buoyant force that is balanced by the weight of the swimmer.

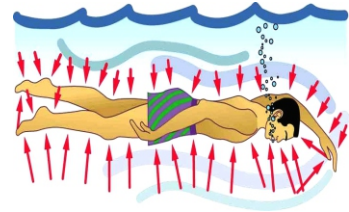



Fig 5.8
Swimmer feels fluid pressure in swimming pool

Factors affecting pressure

Pressure **P** is proportional to the depth, the deeper one dives into water, greater will be the pressure. Twice the depth means twice the pressure (Fig 5.9).

Similarly, pressure also depends upon the density of the material. If a material is five times denser than water, the pressure will be five times greater.

At a depth h in a fluid of density ρ, the pressure p can be written as:

Pressure = depth × density × acceleration due to gravity

$$p = d\rho g \quad \text{.......................(5.3)}$$

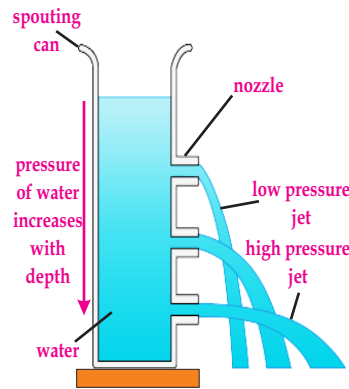
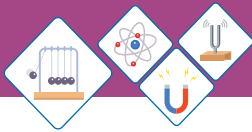
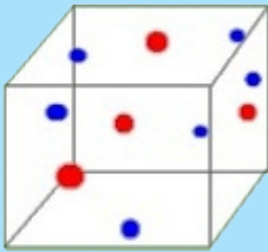
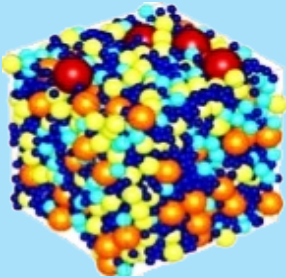



Fig 5.9
Pressure increases with depth

Do You Know!

What is Density?

- Density tells us how tightly matter is packed together.
- If something is packed very tightly together it is considered to be "dense".

More dense sinks and pushes up less dense.

Worked Example 2

Calculate the pressure at a depth of 3m in a swimming pool?

(density of water = $1000kgm^{-3}$).

Step 1: Write down known quantities and quantities to be found.

$d = 3m$

$\rho = 1000kgm^{-3}$

$g = 10ms^{-2}$

$p = ??$

Step 2: Write down formula and rearrange if necessary

$p = d\rho g$

Step 3: Put the values in formula and calculate

$p = 3m \times 1000kgm^{-3} \times 10ms^{-2}$

$p = 30000pa = 3.0 x \times 10^4 pa$

Hence 3.0×10^4pa pressure will be observed at a depth of 3m in the swimming pool.

Worked Example 3

A boy is digging a hole with spade of edge 0.1 cm^2. Calculate the pressure when he is exerting the force of 1000N onto the spade.

Step 1: Write down known quantities and quantities to be found.

$F = 1000N$

$A = 0.1cm^2 = \frac{0.1}{100x100} m^2 = 1.0 x 10^{-5} m^2$

$p = ??$

Step 2: Write down formula and rearrange if necessary

$p = F/A$

Step 3: Put the values in formula and calculate

$$p = \frac{1000N}{1.0 \times 10^{-5} m^2}$$

$$p = 1.0 \times 10^{8} Nm^{-2}.$$

Hence, there will be $1.0 \times 10^{8} Nm^{-2}$ pressure.

Self Assessment Questions:

Q8: A wooden block of dimensions 0.5m×0.6m×1.0m kept on the ground has a mass of 200kg. Calculate the maximum pressure acting on the ground.

Q9: If the density of sea water is 1150 kgm^{-3}, calculate the pressure on a body of 50m below the surface of sea?

Q10: Dam holds water at high altitude. The walls of the dam are made wider at the base. Explain why?

Hydraulic Machine

The machine in which force is transmitted by liquids under pressure is known as hydraulic machine. By the application of relatively small force they produce a greater force.

Pascal's law

The liquid pressure at the surface of the liquid increases when an external force is applied on the surface of the liquid. The increase in the liquid's pressure is transmitted equally in all directions, in similar way it is transmitted equally to the walls of the container in which it is filled. This result leads to a law known as Pascal's law. This law may be stated as:

The pressure applied externally at any point of a liquid enclosed in a container is transmitted equally to all parts of the liquid in container.

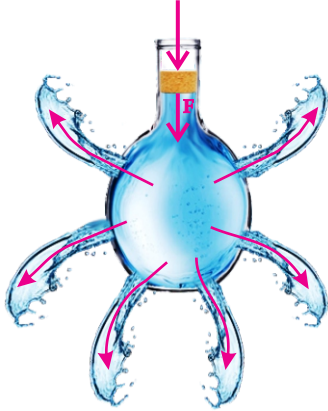
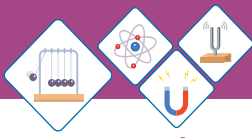



Fig 5.10
Demonstrating pascal's law

It can be demonstrated with the help of a water filled glass vessel having holes around its surface; Fig 5.10. When you apply force through the piston the water rushes out of the holes with the same pressure. The force applied on the piston exerts pressure on water. This pressure is transmitted equally throughout the liquid in all directions. In general, this law holds good for fluids both for liquids as well as gases.

A hydraulic machine works on this principle. Hydraulic brakes, car lifts, hydraulic jacks, forklifts, and other machines make use of this principle.

A hydraulic press is made of two pistons connected by a liquid-filled pipe as shown in Fig 5.11 .

Force increases with hydraulics
$F_2 = F_1 \times (A_2 / A_1)$

F_2

F_1

Piston of area A_1

Piston of area A_2

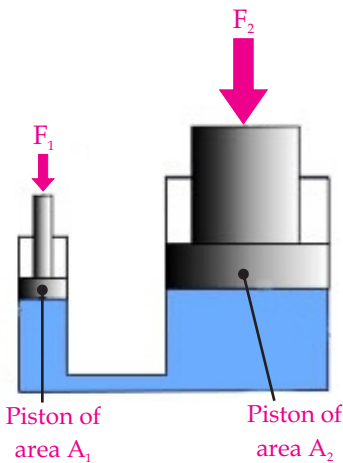



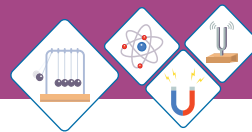
Fig 5.11
A Hydraulic machine

A force of magnitude F_1 is applied to a small piston of surface area A_1. The pressure is transmitted through an incompressible liquid to a larger piston of surface area A_2. Because the pressure must be the same on both sides,

$$p = \frac{F_1}{A_1} = \frac{F_2}{A_2} \quad \text{.......................(5.4)}$$

Therefore, the force F_2 is greater than the force F_1 by a factor A_2/A_1.

By designing a hydraulic press with appropriate areas A_1 and A_2, a large output force can be applied by means of a small input force.

Each side of this equation is the work done by the force. Thus, the work done by F_1 on the input piston equals to the work done by F_2 on the output piston. Thus the principle of conservation of energy applies in the hydraulic press.

Worked Example 4

In a hydraulic lift system, what must be the surface area of a piston. If a pressure of 300 kpa is used to provide an upward force of 2000 N?

Solution

Step:1 Write down known quantities and quantities to be found.

$p = 300kPa = 300 \times 1000Pa = 300000Pa = 300000Nm^{-2}$

$F = 2000N$

$A = ?$

Step:2 Write down formula and rearrange if necessary

$$p = F/A$$

$$A = F/p$$

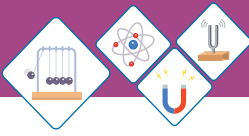
Step:3 Put the values in formula and calculate

$A = 2000N / 300000Nm^{-2} = 0.00667m^2$

Hence the surface area of piston is $0.00667m^2$.

Self Assessment Questions:

Q11. In a hydraulic press, a force of 100 N is applied on the pump of cross-sectional area $0.01m^2$. Find the force that compresses a cotton bale placed on larger piston of cross-sectional area $1m^2$.

Q12. Write down the names of four machines that you have seen working on the principle of pascal's law.

- Forces on an object can cause tensile deformation (stretching) and compressive deformation (squashing).
- An elastic change occurs when an object returns to its original shape and size after the load is removed.
- An extension against load graph shows how a body stretches when a load is applied to it.
- Hooke's Law: The extension in spring is proportional to the load applied to it, provided the limit of elasticity is not exceeded.

$$F = kx$$

- An extension against load graph is a straight line up to the limit of proportionality.
- Pressure is greater when a large force acts on small area.

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

- The pressure in a fluid is greater with large depth, and high density.
- Pressure = depth x density x acceleration due to gravity

$$p = d\rho g$$

- Liquids transmit pressure equally in all directions. This is called Pascal's law.
- The machine in which force is transmitted by liquids under pressure is known as hydraulic machine.

CONCEPT MAP

Force

Force can be defined as a push or a pull that changes or tends to change the state of rest or uniform motion of an object or changes the direction or shape of an object.

Types of Forces

Force (action at distance)

Gravitational force, Electrical force, Magnetic forces, strong nuclear force.

Force (contact forces)

Frictional force; Tension force; Normal Force; Air Resistance Force, Applied Force, Spring Force.

Effect of the force

- Forces can exert the pressure
- Pressure (force per unit area)

Application

Pascal's Law

Demonstrated by using

Hydraulic brakes, Car lifts, hydraulic jacks etc.

Force can bend, stretch or squeeze something to change its shape and size.

Application

Hooke's law $F = kx$

Demonstrated by using

Spring

End of Unit Questions

Section (A) Multiple Choice Questions (MCQs)

1. The springs in brakes and clutches are used
   a) To restore original position
   b) To measure forces
   c) To absorb shocks
   d) To absorb strain energy
2. If the material recovers the original dimensions, when an external force is removed, this deformation is known as ______ deformation.
   a) Inelastic b) Permanent
   c) Elastic d) Irreversible
3. Which of the following material is more elastic?
   a) Rubber b) Glass
   c) Steel d) Wood
4. If a spring stretches easily then its spring constant has ______.
   a) Large value b) Small value
   c) Constant Value d) Both (a) and (b)
5. What is the unit for the spring constant?
   a) Nm b) Nm^{-2}
   c) Nm^{-1} d) Nm^{2}
6. The spring obeys Hooke's law for the earlier extensions and when the spring becomes damaged it does not appear to do so; Fig 5.12. Estimate, from graph, after addition of which weight the spring damaged.
   a) 1.5 N b) 8 N
   c) 1.6 N d) 2.0 N
7. Which of the following is not a unit of pressure?
   a) Pascal b) Bar
   c) Atmosphere d) Newton

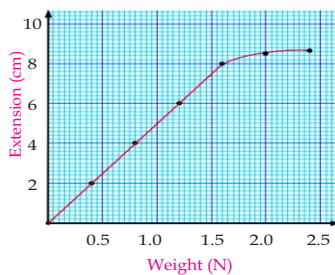
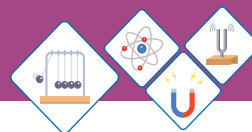



Fig 5.12
Graph between weight and extension for spring

8. If a metal block applies a force of 20 N on an area of 5 cm^2. Find the pressure being applied by the block on the area of ____.
   a) 100 Ncm^{-2} b) 0.8 Ncm^{-2}
   c) 0.25 Ncm^{-2} d) 4 Ncm^{-2}
9. The Fig 5.13 shows a container with three spouts. The container is filled with water. Jets of water pour out of the spouts. Why does the jet of water from the bottom spout goes farthest out from the container?
   a) Pressure decreases with depth.
   b) Pressure increases with depth.
   c) More water available to flow out from the bottom.
   d) Density of water different at different places.

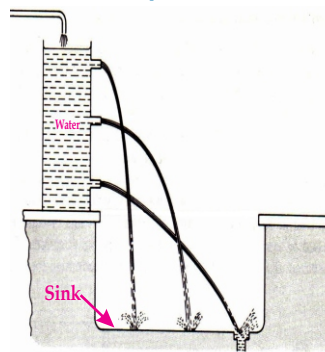



Fig 5.13

Section (B) Structured Questions

Stretching of Spring

1. Some students experimented to find out how a spring stretched when loads were added to it

Table 5.3 For load and extension

Load (N)	0	2	4	6	8	10	12	14
Extension (mm)	0	15	30	45	60	75	90	100

   a) Use these results to plot a graph. (Plot x = load, y = extension in spring).
   b) Use your graph to find
      i) The extension when the load is 3 N;
      ii) The load which produces an extension of 40mm.
2. The variation in extension x of the force F for a spring is shown in Fig 5.14. The point L on the graph is the elastic limit of the spring.
   a) Describe the meaning of elastic limit.

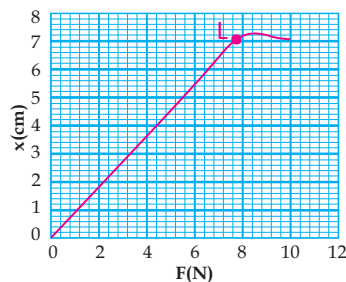
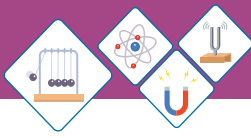



Fig 5.14
Graph between force loadand extension

b) Calculate the force in extending the spring to its elastic limit 'L'.

Hooke's Law

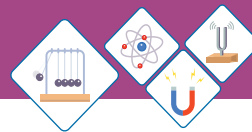
3. State Hooke's law.
4. Calculate the spring constant for a spring which extends by a distance of 3.5cm when a load of 14N is hung from its end.
5. Table 5.4 shows the results of an experiment to stretch a spring.

Table 5.4 For load and extension in spring

Load (N)	Extension (cm)
0.0	0.0
2.0	80.0
4.0	83.0
6.0	86.0
8.0	89.0
10.0	92.0
12.0	93.0

a) Use the result to plot an extension against load graph.
b) On the graph mark the limit of proportionality and state the value of the load at this point.
c) Calculate the spring constant k.
d) Show maximum force at which hooke's law is applicable.

Pressure

6. a) Define the term pressure.
   b) Write down the S.I unit of pressure.

7. Why does pressure increases as you dig deeper; Explain in detail.
8. A boy is pressing a thumbtack into a piece of wood with a force of 20 N. The surface area of head of thumbtack is $1cm^2$ and the cross-section area of the tip of the thumbtack is $0.01cm^2$. Calculate

   a) The pressure exerted by boy's thumb on the head of thumbtack.
   b) The pressure of the tip of the thumbtack on the wood.
   c) What conclusion can be drawn from answers of part (a) and (b)?
9. The Fig 5.15 shows a basic hydraulic system that has small and large pistons of cross section area of 0.005 m^2 and 0.1 m^2 respectively. A force of 20N is applied to small piston. Calculate
   a) The pressure transmitted into hydraulic fluid.
   b) The force at large piston.
   c) Discuss the distance travelled by small and large pistons.

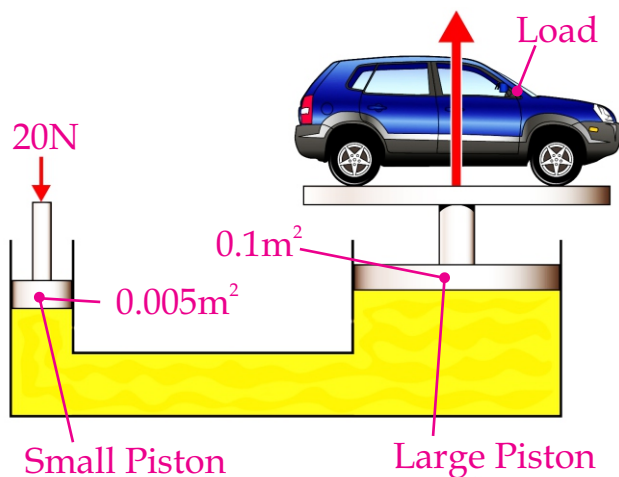



Fig 5.15
A hydraulic system

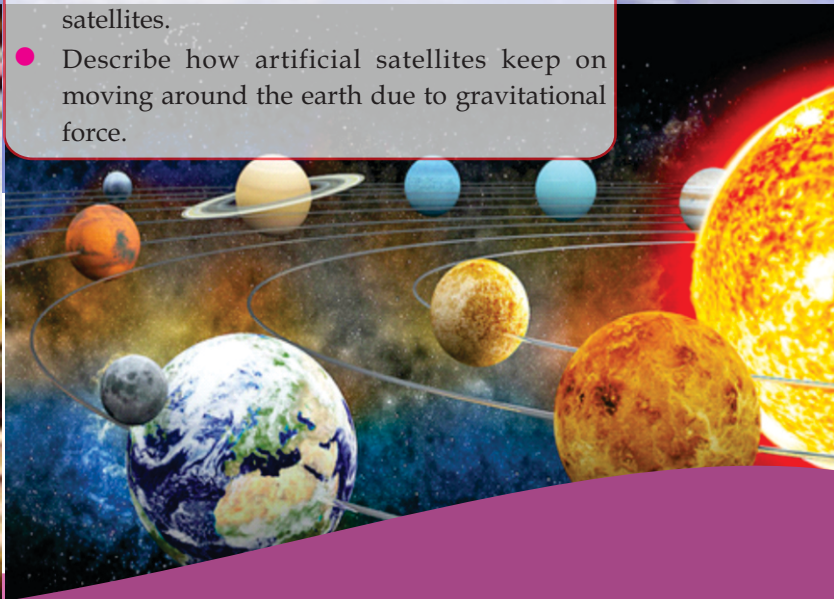
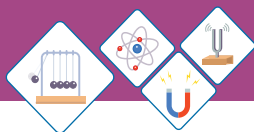
Unit - 6

GRAVITATION

The natural force which pulls every two objects in the universe towards each other is known as “Gravity”. This force acts on all objects which have mass. This force depends upon the masses of the objects. Big masses have high gravitational pull while small masses have low gravitational pull. Gravity of earth hold all objects like buildings, animals, trees, human beings etc on Earth. Moon, stars and planets all have gravity. The gravity causes weight. The weight of an object is smaller at moon than Earth. Gravity causes the satellites and planets to move in their orbits.

Students Learning Outcomes (SLOs)

After learning this unit students should be able to:

- State Newton's law of gravitation
- Explain that the gravitational forces are consistent with Newton's third law.
- Explain gravitational field as an example of field of force.
- Solve problems using Newton's law of gravitation.
- Define weight (as the force on an object due to a gravitational field.)
- Calculate the mass of earth by using law of gravitation.
- Discuss the importance of Newton's law of gravitation in understanding the motion of satellites.
- Describe how artificial satellites keep on moving around the earth due to gravitational force.

Do You Know!

Sir Isaac Newton, was one of the greatest scientist of the world. He made fundamental contributions not only to several branches of Physics (like optics and mechanics) but also to Astronomy and Mathematics. He formulated the laws of motion and law of Universal gravitation.

Why a leaf which drops from a tree always falls on the Earth? Why a ball which is thrown upward comes back to Earth? Which force keeps object around us at their places? Why a body has weight? Which force is responsible for the motion of an artificial satellite around the Earth?

After studying this unit you will be able to find the answers of such questions and other similar questions.

Among famous stories in the history of science one comes from 1666. One day Isaac Newton was sitting in his mother's, garden where he witnessed an apple falling from a tree. The scenario helped him to explore the idea of gravity. Newton successfully discovered the cause of falling bodies. He further revealed that gravity makes the planets to revolve around the sun and it also causes the moon and satellite orbiting around the earth in a specific fashion.

6.1 Newton's Law Of Gravitation

Newton's law of universal gravitation states that:

Everybody in the universe attracts every other body with a force which is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centres.

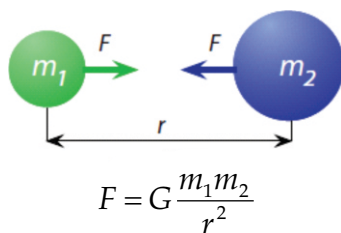
To understand this law, let us consider two bodies of masses m_1 and m_2. The distance between their centers is r (Fig 6.1).

$$F = G\frac{m_1 m_2}{r^2}$$

Fig 6.1
Newton's Law of Universal Gravitation

According to the statement force of attraction between two bodies is directly proportional to the product of their masses. Therefore,

$$F \propto m_1 m_2 \text{ ----------(i)}$$

The gravitational force of attraction is inversely proportional to the square of the distance between the centers of the masses of the bodies. Therefore

$$F \propto \frac{1}{r^2} \quad \text{----------(ii)}$$

Combining equation (i) and equation (ii)

$$F \propto \frac{m_1 m_2}{r^2}$$

$$\mathbf{F = G\frac{m_1 m_2}{r^2}} \quad \text{........................(6.1)}$$

Where 'G' is constant of proportionality known as "Universal gravitational constant". The value of 'G' in SI unit is $6.673 \times 10^{-11}\ Nm^2kg^{-2}$. This is very small value. 'G' remains constant everywhere.

We do not feel the gravitational force of attraction between objects around us due to the very small value of 'G'. But it exists everywhere in the universe.

Difference between "G" and "g".

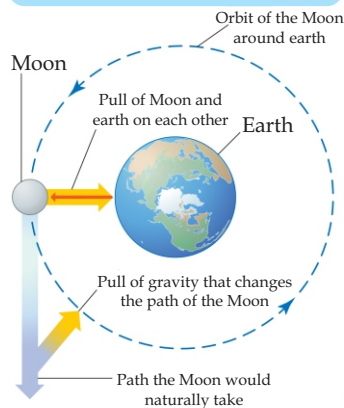
"G"	"g"
It is universal gravitational constant.	It is acceleration due to gravity which determines the gravitational force acting per unit mass.
It has same value everywhere in the universe.	It has different values at different places.
It has value 6.673×10^{-11} Nm^2kg^{-2}	It near earth's surface has value $10 ms^{-2}$ or $10\ Nkg^{-1}$.

Do You Know!

Demonstration of Newton's law of universal gravitation

The pull of the gravity changes the path of the Moon around the Earth.

Weblinks

- https://www.youtube.com/watch?v=Ym6nlwvQZnE
- https://www.youtube.com/watch?v=2PSjARmmL7M

Do You Know!

"G" is also known as Newtonian constant of gravitation or the Cavendish gravitational constant.

Key points

Gravitational force has following characteristics:

i) It is always present between every two objects because of their masses.
ii) It exists everywhere in the universe.
iii) It forms an action-reaction pair.
iv) It is independent of the medium between the objects.
v) It is directly proportional to the product of the masses of objects.
vi) It is inversely proportional to the square of the distance between the centres of the objects.
vii) Hence it follows the "Inverse Square Law".

Worked Example 1

Determine the gravitational force of attraction between two spherical bodies of masses 500kg and 800kg. Distance between their centers is 2 meters.

Solution

Step:1 Write down known quantities and quantities to be found.

$m_1 = 500kg$
$m_2 = 800kg$
$r = 2m$
$G = 6.67 \times 10^{-11} Nm^2kg^{-2}$
$F = ??$

Step:2 Write down formula and rearrange if necessary

$$F = G\frac{m_1 m_2}{r^2}$$

Step:3 Put the values in formula and calculate

$$F = \frac{6.67 \times 10^{-11} Nm^2kg^{-2} \times 500kg \times 800kg}{(2m)^2}$$

$$F = 6.67 \times 10^{-6} N$$

Hence, the gravitational force of attraction between the bodies is $6.67 \times 10^{-6}N$.

Law of Gravitation and Newton's Third law of Motion

According to Newton's law of gravitation, every two objects attract each other with equal force but in opposite direction. As shown in fig 6.2.

From the figure:

$m_1 \rightarrow$ Mass of body A

$m_2 \rightarrow$ Mass of body B

$F_{12} \rightarrow$ Force with which body A attracts body B

$F_{21} \rightarrow$ Force with which body B attracts body A

Then according to this law

$$F_{12} = -F_{21}$$

This shows that, the two forces are equal in magnitude but opposite in direction. Now, if F_{12} is considered as "Action Force" and F_{21} as "Reaction Force". Then by using above equation, it is concluded that "Action equals to reaction but in opposite direction".

Recall that, above statement is in accordance with the Newton's third law of motion which states that "To every action there is always an equal and opposite reaction".

Hence, Newton's law of gravitation is consistent with Newton's third law of motion.

For example, according to Newton's law of Universal gravitation the Earth pulls the Moon with its gravity and the Moon pulls the Earth with its gravity. Therefore they form an action-reaction pair, which is in accordance with Newton's third law of motion.

Do You Know!

Henry Cavendish in 1798 completed the 1st experiment that demonstrated the Newton's Law of universal gravitation. This happens more than a century after Newton had announced law of universal gravitation.

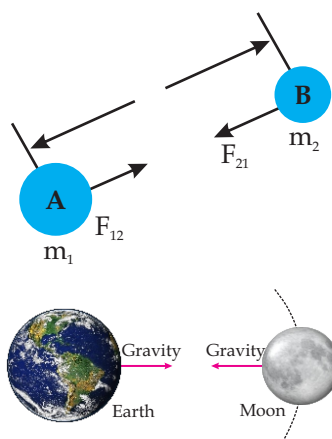



Fig 6.2

Demonstration of Newton's law of universal gravitation in accordance with Newton's third law of motion.

Gravitational Field

Gravitational field can be described as:

"A gravitational field is a region in which a mass experiences a force due to gravitational attraction".

The earth has an attractive gravitational field around it. Any object near the Earth experience this

Activity

Measure the masses of your copy and pen and then calculate the gravitational force of attraction between them.

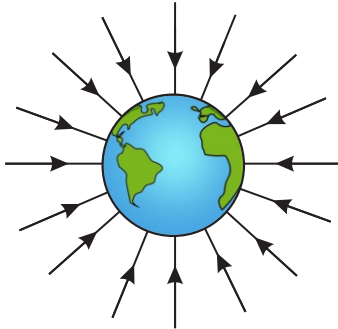
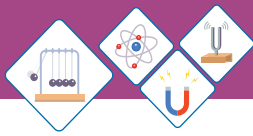



Fig 6.3
Gravitational field around the Earth is directed toward center of earth from all direction

Point to Ponder

- Does the whole solar system works in a push and pull network?

Planet	Value of g ms^{-2}
Earth	10
Moon	1.62
Venus	8.87
Mars	3.77
Jupiter	25.95
Sun	274
Mercury	3.59
Saturn	11.08
Uranus	10.67
Neptune	14.07

Table 6.1
Acceleration due to gravity "g" at different planets.

force which is due to Earth's gravity. This field is directed towards the centre of the Earth as shown in fig 6.3.

This field is strongest near the surface of the Earth and gets weaker as we move farther & farther away from the Earth. This force is called the "Field Force" because it acts on all objects whether they are in contact with Earth's surface or not. So, it is a non-contact force. For example, it acts on an aeroplane either it is standing on Earth's surface or flying in the sky.

A body of mass one kilogram (1kg) on Earth experiences a force of about ten newton (10N) due to Earth's gravitational field. This force determines the gravitational field strength which is defined as:

Gravitational field strength 'g' is the gravitational force acting per unit mass.

The gravitational field strength "g" is approximately 10 Newton per kilogram $10Nkg^{-1}$.

The gravitational field strength "g" is different at different planets. For example, the gravitational field strength "g" on the surface of Moon is approximately 1.6 Newton per Kilogram $1.6Nkg^{-1}$. Acceleration due to gravity "g" at different planets is shown in the table 6.1.

Self Assessment Questions:

Q1: What will be the effect on gravitational pull between two objects if medium between them is changed?

Q2: Which force causes the moon to move in orbit around earth?

6.2 WEIGHT

We know that all the objects which are thrown upward in the air, fall back to the ground. Have you noticed why this is so?

The force applied by the Earth's gravitational field, pulls the objects downward. Weight is another name for the Earth's gravitational force on the objects. Therefore weight can be defined as:

The weight of an object is the measurement of gravitational force acting on the object.

Weight 'W' of an object of mass 'm', in a gravitational field of strength 'g' is given by the relation:

$$W = mg \quad (6.2)$$

Like other forces weight is also measured in Newton's (N). Spring balance is used to measure weight of an object; Fig 6.4.

An object of mass 1kg has a weight of 9.8N near the surface of Earth. Though 10N is accurate enough for many calculations. Therefore we use 10N in this book. The objects with larger masses may have larger weights. Your weight vary slightly from place to place, because Earth's gravitational field strength varies at different places. The weight of the object changes as it moves away from the Earth. The weight of the object is different at different planets. For example: you will have less weight at Moon because Moon's gravitational field is weaker than Earth.

Fig 6.4
Spring balance

Do You Know!

'Gravity' is taken from Latin word 'gravitas' means 'weight'.

Activity

The teacher should encourage and facilitate the students in the class to measure their masses and then calculate their weights on Earth, Moon and Mars.

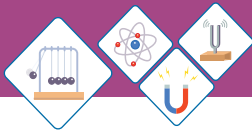
Worked Example 2

Calculate the weight of Rumaisa, who has a mass of 65kg standing at the ground. The strength of gravitational field on Rumaisa is 10 Newton per kilogram?

Solution

Step:1 Write down known quantities and quantities to be found.

$m = 65kg$

$g = 10Nkg^{-1}$

$W = ??$

British scientist George Atwood (1746-1807) used two masses suspended from a fixed pulley, to study the motion and measure the value of 'g'. This is named as "Atwood Machine".

Step:2 Write down formula and rearrange if necessary

$$W = mg$$

Step:3 Put the values in formula and calculate

$$W = 65kg \times 10Nkg^{-1}$$

Hence, the weight of Rumaisa is 650 Newton.

Self Assessment Questions:

Q3: Why weight of an object is different at different planets?

Q4: What is the actual value of 'g' near the surface of Earth?

Q5: The strength of gravity on the Moon is 1.6 Nkg^{-1}. If an astronaut's mass is 80kg on Earth, what would it be on the Moon?

Q6: If you go on a diet and lose weight, will you also lose mas? Explain.

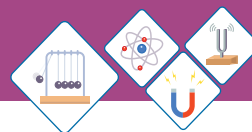
6.3 Mass of Earth

Mass of Earth can not be measured directly by placing it on any weighing scale. But it can be measured by an indirect method. This method utilizes the Newton's law of universal gravitation. Let us consider; Fig 6.5, in which a small ball is placed on the surface of Earth.

Fig 6.5
Weight of a ball is equal to the gravitational force between the ball and the Earth.

m $\rightarrow$ Mass of the ball.
M_E $\rightarrow$ Mass of Earth.
G $\rightarrow$ Universal gravitational constant.
R_E $\rightarrow$ Radius of earth; which is also the distance between the ball and centre of earth.

Then according to Newton's law of universal gravitation, the gravitational force F of the Earth acts on the ball is:

$$F = G\frac{mM_E}{R_E^2} \quad \text{.....................(6.3)}$$

Whereas the force with which Earth attracts the ball towards its centre is equal to the weight of the ball. Therefore

$$F = W = mg \quad \text{.....................(6.4)}$$

Comparing equation (6.3) and (6.4); we get:

$$mg = G\frac{mM_E}{R_E^2}$$

Re-arrangment of above equation gives

$$M_E = \frac{gR_E^2}{G} \quad \text{.....................(6.5)}$$

Numerical values of the constants at right hand side of equation (6.5) are:

$g = 10Nkg^{-1}$

$R_E = 6.38 \times 10^6 m$

$G = 6.673 \times 10^{-11} Nm^2kg^{-2}$

Substituting these values in equation (6.5), we get:

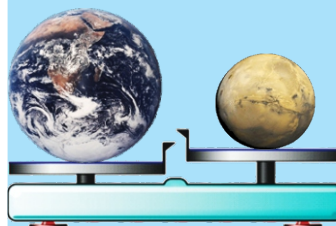
$$M_E = \frac{10Nkg^{-1} \times (6.38 \times 10^6 m)^2}{6.673 \times 10^{-11} Nm^2kg^{-2}}$$

$$M_E = 6.0 \times 10^{24} kg.$$

Thus, mass of Earth is 6.0×10^{24}kg.

Do You Know!

Ocean tides are caused by the gravity of Moon.

Do You Know!

The Earth has 9.3 times more mass than Mars

Worked Example 3

Calculate the acceleration due to gravity on a planet that has mass two times to the mass of Earth and radius 1.5 times to the radius of Earth. If the acceleration due to gravity on the surface of Earth is $10ms^{-2}$. Calculate acceleration due to gravity on the planet?

Solution

Step 1: Write down known quantities and quantities to be found.

Mass of the planet = $M_p = 2M_E$

Mass of the Earth = $M_E = 6.0 \times 10^{24}$kg

Activity

Calculate the mass of the Earth if acceleration due to gravity; g = $9.8ms^{-2}$.

Radius of the planet = $R_p = 1.5\ R_E$
Radius of the Earth = $R_E = 6.38 \times 10^6 m$
Universal gravitational constant
$= G = 6.673 \times 10^{-11} Nm^2kg^{-2}$
Acceleration due to gravity on the Earth = $g_E = 10ms^{-2}$
Acceleration due to gravity on the planet = g_p = ??

Step 2: Write down formula and rearrange if necessary

$$g_E = \frac{GM_E}{R_E^2}$$

For the planet:

$$g_p = \frac{GM_p}{R_p}$$

Step 3: Put the values in formula and calculate:

$$g_p = \frac{6.673 \times 10^{-11} Nm^2kg^{-2} \times 2 \times 6.0 \times 10^{24} kg}{(1.5 \times 6.38 \times 10m^6)^2}$$

$$g_p = 8.74ms^{-2}$$

Hence, acceleration due to gravity on the planet is $8.74ms^{-2}$.

Mass and Radius of different planets.

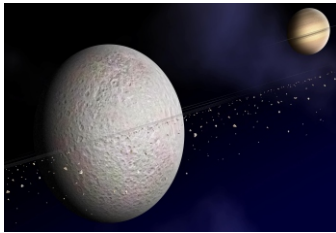



Fig 6.6 (a)
A natural satellite Moon revolving around the Earth

Fig 6.6 (b)
An artificial satellite revolving around the Earth

Self Assessment Questions:

Q7: What will be the value of acceleration due to gravity on the surface of earth if its radius reduces to half?

Q8: What will be acceleration due to gravity on the surface of earth f its mass reduces by 25%?

Q9: What will be the mass of a planet whose radius is 20% of the radius of earth?

6.4 Artificial Satellites

A satellite is an object that revolves around a planet. Satellites are of two types:

1. Natural satellites Fig 6.6 (a).
2. Artificial satellites Fig 6.6 (b).

Natural Satellites	Artificial Satellites
The planet which revolves around another planet naturally is called "Natural Satellite".	The object which are sent into space by scientists to revolve around the Earth or other planets are called "Artificial Satellite".
E.g Moon is a natural satellite because it revolves around the Earth naturally.	E.g. Sputnik-1, Explorer-1 are amongst the artificial satellites.

Artificial satellites are used for different purposes like

- For communication.
- For making star maps.
- For making maps of planetary surfaces.
- For collecting information about weather.
- For taking pictures of planets, etc.

Artificial satellites carry instruments, passengers or both to perform different experiments in space.

Artificial satellites have been launched into different orbits around the Earth. There are different types of orbits like:

- For communication.
- Low- Earth orbit.
- Medium- Earth orbit.
- Geostationary orbit.
- Elliptic orbit.

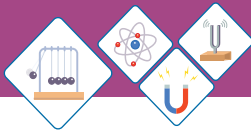
These orbits are characterized on the basis of different parameters like, their distance from the Earth, their time period around the Earth etc.

An artificial satellite which completes its one revolution around the Earth in 24 hours is used for communication purpose. As Earth also completes its one rotation about its axis in 24 hours, therefore the above satellite appears to be stationary with respect to

Interesting Information

Mass and radius of different objects		
Planet / Star	Mass (Kg)	Radius (m)
Sun	1.99×10^{30}	6.96×10^{8}
Moon	7.35×10^{22}	1.74×10^{6}
Mercury	3.30×10^{23}	2.44×10^{6}
Venus	4.87×10^{24}	6.05×10^{6}
Earth	5.97×10^{24}	6.38×10^{6}
Mars	6.42×10^{23}	3.40×10^{6}
Jupiter	1.90×10^{27}	6.91×10^{7}
Saturn	5.68×10^{26}	6.03×10^{7}
Uranus	8.68×10^{25}	2.56×10^{7}
Neptune	1.02×10^{26}	2.48×10^{7}

Do You Know!

First artificial satellite was Sputnik-1 which was sent into space by Soviet Union (Russia) on 4th October 1957.

Earth. Its orbit is therefore called "Geostationary orbit". As it is used for communication purpose, therefore it is known as "Communication Satellite".

Newton's Law of Gravitation in the motion of satellite

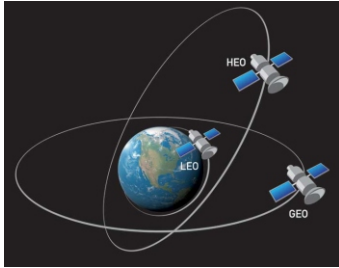



Fig 6.7
Motion of satellites in different orbits

The curved path along which a natural or artificial satellite revolves around a planet is called an "orbit"; (Fig 6.7). Rockets are used to put satellites into orbits in space. The Newton's law of gravitation has an important role in the motion of satellite in its orbit, because the gravitational pull of Earth on the satellite provides the centripetal force needed to keep a satellite in orbit around some planet.

Let us consider the motion of a satellite which is revolving around the Earth; Fig 6.8. In the figure:

m → Mass of the satellite.
M → Mass of Earth.
R → Radius of Earth
h → Height(altitude) of satellite from the surface of Earth.
$r = R + h$ → Radius of orbit.

Then, as we already discussed:

Centripetal force = Gravitational force

$$\text{or} \quad F_C = F_G \longrightarrow \text{(i)}$$

$$\because \quad F_C = \frac{mv^2}{r} \quad \text{and}$$

$$F_G = \frac{GmM}{r^2}$$

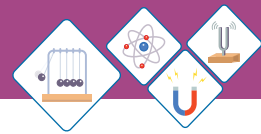
Substituting the values of F_C and F_G in equation (i):

$$\frac{mv^2}{r} = \frac{GmM}{r^2}$$

$$v^2 = \frac{GM}{r} \qquad [\because r = R + h]$$

$$\therefore \quad v^2 = \frac{GM}{R+h}$$

Do You Know!

The height of a geostationary satellite is about 42,300 km from the surface of the Earth. Its velocity with respect to Earth is zero.

$$\mathbf{v} = \sqrt{\frac{\mathbf{GM}}{\mathbf{R+h}}} \quad ....(6.6)$$

This gives the velocity that a satellite must possess when orbiting around Earth in an orbit of radius (r = R+h).

This shows that, the speed of the satellite is independent of its mass. Hence every satellite whether it is very massive (large) or very light (small) has the same speed in the same orbit.

The time required for a satellite to complete one revolution around the Earth in its orbit is called its time period "T". The time period of a satellite can be calculated as:

$$\because \quad T = \frac{2\pi r}{v} \text{-----------(i)}$$

The velocity of satellite is given by equation (6.6) as:

$$v = \sqrt{\frac{GM}{R+h}}$$

Substituting it in equation (i)

$$\therefore \quad T = \frac{2\pi r}{\sqrt{\frac{GM}{R+h}}} \qquad \because \quad r = R+h$$

$$\therefore \quad T = 2\pi\, r\sqrt{\frac{r}{GM}}$$

$$\therefore \quad \mathbf{T = 2\pi\sqrt{\frac{r^3}{GM}}} \quad ....(6.7)$$

Equations (6.7) gives the expression for the time period of a satellite orbiting around the Earth. Thus, Newton's law of gravitation helps to describe the motion of a satellite in an orbit around the Earth.

Motion of Artificial Satellite around the Earth

The satellites are put into their orbits around the Earth by rockets. When a satellite is put into orbit, its speed is selected carefully and correctly. If speed is not

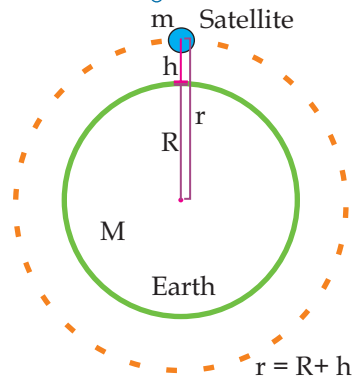



Fig 6.8
A Satellite is orbiting around the Earth

Weblinks

How satellite is launched into an orbit:

https://www.youtube.com/watch?v=8t2eyEDy7p4

chosen correctly then the satellite may fall back to Earth or its path may take it further into orbit. During the motion of a satellite in the orbit the gravitation pull of Earth on it is always directed towards the centre of Earth.

Newton used the following example to explain how gravity makes the orbiting possible.
Imagine a cannonball launched from a high mountain; Figure 6.8; shows three paths the ball can follow.

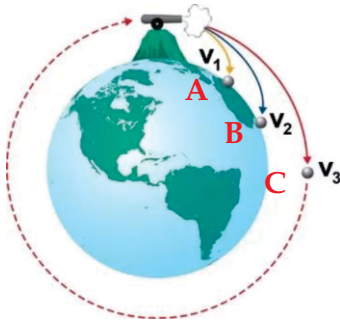



Fig 6.8
A cannon ball launched from high mountain

Path A	Path B	Path C
The canon ball is launched at a slow speed.	The canon ball is launched at a medium speed.	The canon ball is launched at a high speed.
The canon ball will fall back to Earth.	The canon ball will fall back to Earth.	The canon ball will not fall back to Earth instead it orbits around the Earth.

Above example shows that, for an artificial satellite to orbit the Earth and to retrace its path it requires certain orbital velocity. The orbital velocity is defined as:

The velocity required to keep the satellite into its orbit is called "Orbital Velocity"

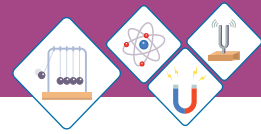
The gravitational pull of Earth on a satellite provides the necessary centripetal force for orbital motion. Since this force is equal to the weight of satellite, '$W_s = mg$', therefore

$$F_C = W_S \text{ ----------- (i)}$$

and, $$W_S = mg_h$$

where,
m → Mass of the satellite.
g_h → Acceleration due to gravity at height 'h' from the surface of Earth.

Do You Know!

Tides in ocean result from the gravitational attraction of sun and moon. Sun's gravitational attraction to the Earth is 177 times greater that of the moon to the Earth

The centripetal force 'F_C' on the satellite is:

$$F_C = \frac{mv^2}{r}$$

Substituting the values of 'F_C' and 'W_S' in equation (i):

$$\frac{mv^2}{r} = mg_h$$

$$\therefore \quad v^2 = g_h r$$

$$\therefore \quad v = \sqrt{g_h r}$$

$$\because \quad r = R + h$$

$$\therefore \quad \mathbf{v = \sqrt{g_h (R + h)}} \quad ....(6.8)$$

If satellite is orbiting very close to the surface of Earth then: $h << R$

In this case orbital radius may be considered equal to radius of Earth.

Therefore, $R + h = R$

Also $g_h = g$

and $v = v_C$

Where,

$v_C \rightarrow$ Critical velocity

$g \rightarrow$ Acceleration due to gravity on the surface of Earth.

In terms of above factors equation (6.8) becomes:

$$\mathbf{v_C = \sqrt{gR}} \quad ....(6.9)$$

This is known as "Critical velocity". It is defined as:

The constant horizontal velocity required to put the satellite into a stable circular orbit around the Earth.

It is also known as orbital speed or proper speed.

If

$$g = 10 ms^{-2}$$

$$R = 6.38 \times 10^6 m$$

Then equation (6.9) becomes.

$$v_c = \sqrt{gR} = \sqrt{10ms^{-2} \times 6.38 \times 10^6 m}$$
$$v_c = 7.99 \times 10^3 ms^{-1}$$
or $$v_c = 8.0kms^{-1}$$

It should be noted that as the satellite get closer to the Earth, the gravitational pull of the Earth on it gets stronger.
So, the satellites in order to stay in an orbit closer to Earth needs to travel faster as compare to those satellites in the farther orbits.

Worked Example 4

Calculate the speed of a satellite which orbits the Earth at an altitude of 1000 kilometres above Earth's surface?

Solution

Step: 1 Write down known quantities and quantities to be found:

$$M_{Earth} = M = 6.0 \times 10^{24} kg$$
$$R_{Earth} = R = 6.38 \times 10^6 m$$
$$h = 1000km = 1000 \times 10^3 m = 1 \times 10^6 m$$
$$G = 6.673 \times 10^{-11} Nm^2kg^{-2}$$
$$v = ??$$

Step:2 Write down formula and rearrange if necessary:

$$v = \sqrt{\frac{GM}{R+h}}$$

Step:3 Put the values in formula and calculate:

$$v = \sqrt{\frac{6.673 \times 10^{-11} Nm^2kg^{-2} \times 6.0 \times 10^{24} kg}{6.38 \times 10^6 m + 1 \times 10^6 m}}$$
$$v = 7.36 \times 10^3 ms^{-1}$$

Hence, the orbital speed of satellite is $7.36 \times 10^3 ms^{-1}$.

Self Assessment Questions:

Q10: Write down any four uses of artificial satellites.

Q11: What is Geostationary orbit?

Q12: Why the two satellites of different masses have same speed in the same orbit?

- The gravitational force (pull) of Earth is known as gravity.
- Everybody in the universe attracts every other body with a gravitational force of magnitude

$$F = \frac{Gm_1m_2}{r^2}$$

- Gravitational force forms an action-reaction pair. Newton's law of gravitation is consistent with Newton's third law of motion.
- "G" has constant value through out the universe.
- "g" has different values at different places.
- A gravitational field is a region in which a mass is attracted due to gravitational attraction.
- Weight of an object is the gravitational pull of Earth acting on it. Mathematically, W = mg.
- Mass of Earth is 6.0×10^{24}kg.
- A satellite is an object that revolves around a planet.
- Natural satellite is a planet that revolves around another planet naturally, like Moon is natural satellite of Earth.
- An artificial satellite is an object which is sent to space to revolve around a planet, like Sputnik-1, Meteosat are artificial satellites of Earth.
- Critical velocity is the constant horizontal velocity needed to put a satellite into an stable circular orbit around the Earth.

Gravitation

Gravity
Natural force between every two bodies in the universe

Gravitational field is a field of force

"g" Acceleration due to gravity

Weight W=mg

Newton's law of universal gravitation.
$$F = \frac{Gm_1m_2}{r^2}$$

"G" Universal gravitational constant

Types of Satellites

- Natural Satellites
- Artificial Satellites

Consistent with Newton's third law of motion. Because the force form an action-reaction pair.

Mass of Earth
$$M_E = \frac{gR_E^2}{G}$$

Motion of Satellites

Motion of Artificial satellite due to gravitational force

Critical velocity

End of Unit Questions

Section (A) Multiple Choice Questions (MCQs)

1. The motion of a falling ball towards Earth is due to the -----------.
   a) Weightlessness
   b) Gravitational force
   c) Acceleration due to gravity
   d) Both 'a' and 'b'
2. Newton's law of gravitation holds between every two objects on the -----------.
   a) on Earth b) on Jupiter
   c) on Moon d) on Universe
3. Numerical value of G is -------------.
   a) $G = 6.673 \times 10^{-11} Nm^2\ kg^{-2}$
   b) $G = 6.673 \times 10^{11} Nm^2\ kg^{-2}$
   c) $G = 6.763 \times 10^{-11} Nm^2\ kg^{-2}$
   d) $G = 6.763 \times 10^{11} Nm^2\ kg^{-2}$
4. Gravitational field of Earth is directed --------------.
   a) towards the Earth b) towards the Sun
   c) towards the Moon d) away from Earth
5. -------------------- was the first scientist who gave the concept of gravitation.
   a) Einstein b) Newton
   c) Faraday d) Maxwell
6. According to Newton's law of universal gravitation force $\propto$ _______.
   a) m_1m_2 b) $\frac{1}{r^2}$
   c) r^2 d) Both (a) and (b)
7. Gravitational force is always -------------.
   a) Repulsive b) Attractive
   c) Both d) None of these

8. Numerical value of ----------------- remains constant every where.
   a) g b) G
   c) F d) W
9. Gravitation force is ------------- of the medium between the objects.
   a) Dependent b) Independent
   c) Both 'a' and 'b' d) None of these
10. Near Earth's surface g = -------------.
   a) $10ms^{-2}$ b) $1.6ms^{-1}$
   c) Both (a) and (b) d) None of these
11. Newton's law of gravitation is consistent with Newton's ------------------ law of motion.
   a) 1^{st} b) 2^{nd}
   c) 3^{rd} d) All of them
12. Spring balance is used to measure ---------------.
   a) Mass b) Weight
   c) Elasticity d) Density
13. Your weight as measured on Earth will be --------- on Moon.
   a) Increased b) Decreased
   c) Remains same d) None of these
14. Mass of Earth is ----------------.
   a) 6.0×10^{23}kg b) 6.0×10^{24}kg
   c) 6.0×10^{25}kg c) 6.0×10^{26}kg
15. ------------- is a natural satellite.
   a) Earth b) Jupiter
   c) Moon d) Mars
16. A communication satellite completes its one revolution around the Earth in --------------- hours.
   a) 6 b) 12
   c) 18 d) 24
17. The velocity of a satellite is ------------- of its mass.
   a) Independent b) Dependent
   c) Equal d) Double

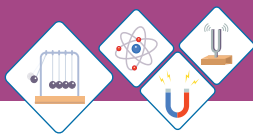
18. ----------------- are used to put satellites into orbits.
    a) Helicopter b) Aeroplane
    c) Rocket d) None of these
19. The critical velocity v_C= --------------.
    a) gR b) $\frac{g}{R}$
    c) $\sqrt{gR}$ d) $\sqrt{\frac{g}{R}}$

Section (B) Structured Questions

Newton's Law of Gravitation

1. a) Why we do not feel the gravitational force of attraction from the objects around us?
   b) Define Gravitational field with an example.
2. a) Write down any three characteristics of Gravitational force?
   b) Define gravitational field strength.
3. a) State & explain Newton's law of gravitation?
   b) Define 'field force'.
4. Determine the gravitational force of attraction between Urwa and Ayesha standing at a distance of 50m apart. The mass of Urwa is 60kg and that of Ayesha is 70kg.

Weight

5. a) Why weight of an object does not remain same every where on Earth?
   b) Why the unit of weight is Newton? Explain.
6. a) Define weight and write down its equation?
   b) Weight of Rani is 450N at the surface of Earth. Find her mass?
7. Weight of Naveera is 700N on the Earth's surface. What will be Naveera's weight at the surface of Moon?

8. a) Your weight decreases as you go up at high altitudes, without dieting. Explain.
   b) If you step on a scale and it gives reading 55kg, is that a measure of your weight. If not then which physical quantity it shows?

Mass of Earth

9. Calculate the mass of Earth by using Newton's law of gravitation.
10. If "M_E" is the mass of Earth, "R_E" radius of Earth, "G" is universal gravitational constant, then find acceleration due to gravity "g";
    i) On the surface of Earth.
    ii) At the centre of Earth.
11. A planet has mass four times of Earth and radius two times that of Earth. If the value of "g" on the surface of Earth is $10ms^{-2}$. Calculate acceleration due to gravity on the planet.
12. Evaluate the acceleration due to gravity in terms of mass of Earth "M_E", radius of Earth "R_E" and universal gravitational constant "G":
    i) At a distance, twice the Earth's radius.
    ii) At a distance, one half the Earth's radius.

Artificial Satellite

13. a) Calculate the speed of a satellite which orbits the Earth at an altitude of 400 kilometers above Earth's surface.
    b) Write the name of any one natural satellite.
14. a) Write down the names of four different types of orbit.
    b) Define the terms
       i) Critical Velocity.
       ii) Communication Satellite.

15. Derive the expression for the motion of a satellite.

$$v = \sqrt{\frac{GM}{R+h}}$$

16. a) Differentiate between the natural satellite and artificial satellite.
    b) Name the parameters on the basis of which orbits are characterized .

Unit - 7

PROPERTIES OF MATTER

Matter is made up of tiny particles called molecules.
Matter exists in different states. three basic states of matter are solid liquid and gas.
The properties of matter in these states can be described on the basis of the forces and distances between their molecules and energy of the molecules..
The temperature and pressure of a gas depends upon the motion of its molecules.
A change in volume of a fixed mass of a gas at constant temperature is caused by a change in pressure applied to the gas.
This fact is used in many fields of daily life. For example, in using syringe, in pumping air to the tyre through a bicycle pump, in spraying color etc.
Matter can change its state and water is the best example of it.

Students Learning Outcomes (SLOs)

After learning this unit students should be able to:

- Describe States of matter.
- State kinetic molecular model of matter
- Explain the kinetic model in terms of forces between particles
- Explain the behavior of gases
- Calculate changes in pressure and volume

$$p_1 V_1 = p_2 V_2$$

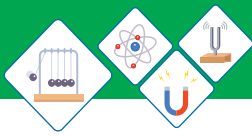



Fig 7.1 (a)

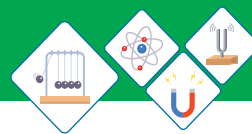
Fig 7.1 (b)

Fig 7.1 (c)

A balloon kept under sunlight shattered, why? Why a hot coffee or tea in a cup became cold as the time passes? Clothes dry up quickly under sunlight? Honey is thicker than water, why?

Why do water and milk or other liquids boil at different temperatures? Why do water and milk take the shapes of the container in which they are poured? Have you ever think that when you sit at your chair or bed, their foams compresses but their wooden frame do not?

After studying this unit you will be able to find the answers of such questions and other similar questions and develop the clear concepts.

7.1 STATES OF MATTER

There are three states of matter. These states are solid, liquid and gas. All the material objects around us belong to any one of these states. Water is the best example of three states of matter.

- The solid state of water is ice figure. 7.1(a). Ice exists in many forms like, ice cubes, snow, glaciers and icebergs.
- The liquid state is water itself figure. 7.1(b). Water is found in oceans, rivers and underground deposits.
- The gaseous state of water is steam. The "white smoke" that you see in figure. 7.1(c) is, in fact, a small cloud formed by water vapours in air above the cup.

These states have different properties which are listed in the following table.

Table 7.1 Properties of Matter

States of Matter	Shape	Volume	Density	Compressibility
Solid	Fixed	Fixed	High	Incompressible
Liquid	Not fixed	Not fixed	High	Incompressible
Gas	Not fixed	Not fixed	Low	Compressible

Addition or removal of a certain amount of energy can change the state of a matter. The terms for these changes in the state are:

Melting: conversion from solid to liquid.
Boiling: conversion from liquid to gas.
Condensing: conversion from gas to liquid.
Freezing: conversion from liquid to solid.
Evaporation: conversion from liquid to gas.

Evaporation is different from boiling.

Evaporation is a process by which a liquid becomes a gas at temperatures below its boiling point.

For example, drying of wet clothes, drying of wet floor etc. Conversion of matter between three states involves physical changes and not chemical changes.

Why liquids and gases take the shapes of their containers while solids have definite shapes? Why do different substances boil and melt at different temperatures? Why can gases be compressed easily while solids and liquids cannot?

The answers of the above and such other questions can be obtained by considering the arrangements of the particles in these states and how these particles are able to move about. This is explained by the kinetic molecular theory of matter.

Kinetic Molecular Model of Matter

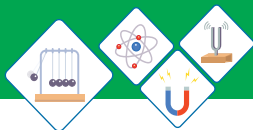
The kinetic molecular model of matter is,

Matter is made up of tiny particles called atoms, or group of atoms called molecules. These molecules are always in continuous random motion.

According to this model particles are in continuous motion. Thus an alternative name for model is 'The particle model of matter'.

The evidence of molecular motion is Brownian motion.

Do You Know!

Water is different from other substances because it is less dense in its solid state (ice), than its liquid state (water).

Weblinks

Web link of Brownian motion.

http://www.phyntau.edu

Solid

Fig 7.2 (a)

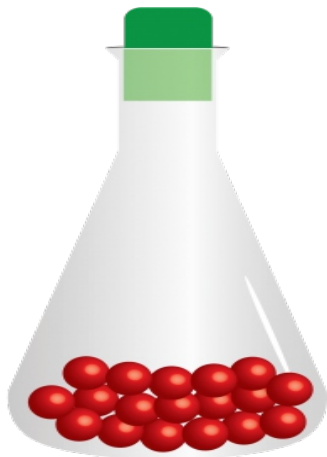
Liquid

Fig 7.2 (b)

Brownian Motion

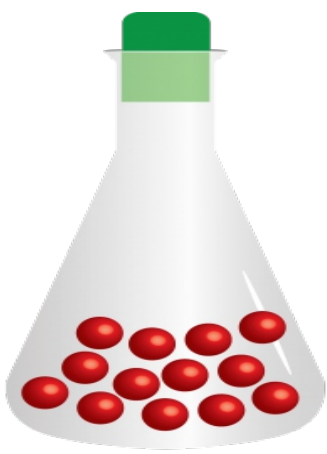
The evidence of molecular motion first discovered by the botanist Robert Brown in 1827. He observed the irregular motion of pollen grains suspended in water and deduced that the water molecules were in constant, random motion. This irregular motion caused by water molecules is called "Brownian motion" named after the scientist.

The kinetic molecular theory explains the physical properties of solids, liquids and gases by considering the position and motion of molecules.

The particles in **solids** (Fig7.2a) have following features:

- The molecules are closely packed together and occupy minimum space.
- The molecules usually arranged in a regular pattern called lattice.
- There is a large number of particles per unit volume. That is why solids have the highest densities.

The movement of particles in solids have following features:

- The forces of attraction between particles are very strong.
- The particles are not able to change positions.
- The particles vibrate about fixed positions thus are not entirely stationary.
- This explains why solids have fixed shapes and volumes.

The particles in **liquids** (Fig 7.2b), have following features:

- The molecules are slightly further apart compared to that of solids.
- The molecules occur in clusters.

- There is slightly less number of particles per unit volume compared to solids.
- This why liquids have relatively high densities.

The movement of particles in liquids have following features:

- The forces of attraction between particles are strong.
- The particles are free to move about within the liquid.
- These features explain why liquids have fixed volumes, but take the shape of the container.

The particles in **gases** (Fig 7.2c), have following features:

- The molecules are very far apart.
- The molecules are arranged randomly and are free to move with very high speeds.
- There is small number of particles per unit volume.

The movement of particles in gases has following features:

- The forces of attraction between particles are negligible.
- The particles are able to move freely in random directions at very high speeds.
- The particles occupy any available space.

Do You Know!

Human body consists of all three states of matter.

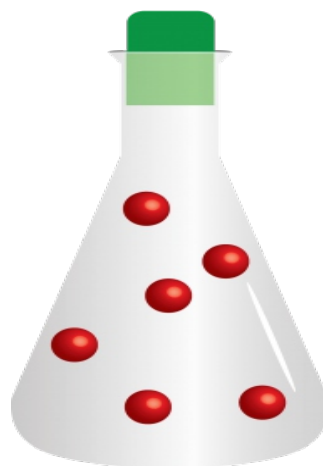
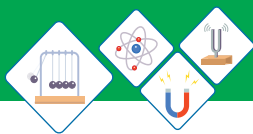
1. Solid in the form of organs.
2. Liquid in the form of blood.
3. Gas in the form of Oxygen and carbondioxide for respiration.

Gas

Fig 7.2 (c)

SELF ASSESSMENT QUESTIONS:

Q1: Explain why the measurement of volume of a given liquid remains same although it is measured by measuring cylinders of different shapes and sizes.

Q2: What is the difference between evaporation and boiling?

Q3: What is the difference between three states of matter? in terms of the spacing between the molecules.

7.2 FORCES AND KINETIC THEORY

Why some materials are solid and liquid while others are gases at room conditions?

Forces between the molecules are responsible for the different states of matter as well as for the physical properties. According to the Kinetic molecular model molecules of gases have large kinetic energy as a result there are no forces of attraction between them as a result molecules of gases can move freely and go farther apart. This is why gases can occupy any available space and can be compressed easily. Boiling and melting points of gases are also very low because of this reason. The molecules of liquids as compared to that of the gases have less kinetic energy hence intermolecular forces come into play. That is why the molecules of liquids are very close to each other but still free to move. therefore liquids do not have fixed shape but fixed volume. The melting and boiling points of liquids are also high as compared to gases. The molecules of solids have extremely lowest energies therefore experience strong attractive forces and can not move freely but only have small vibrations about mean positions. this gives solid a fixed shape and volume. That is why densities, melting and boiling points of solids are very high.

As a result we are able to convert water into ice, cream into ice cream, natural gas into compressed natural gas 'CNG' etc.

The state of a substance can be changed either by heating or by cooling it. on the other hand when a solid substance (Fig7.3) is heated, the molecules start to vibrate more and more strongly. Eventually, the molecules vibrate more violently and inter molecular forces become weak. As a result 'material becomes a

liquid,'if process of heating is continued further, then molecules have sufficient energy to overcome all of the attractive forces as a result 'substance becomes a gas'.

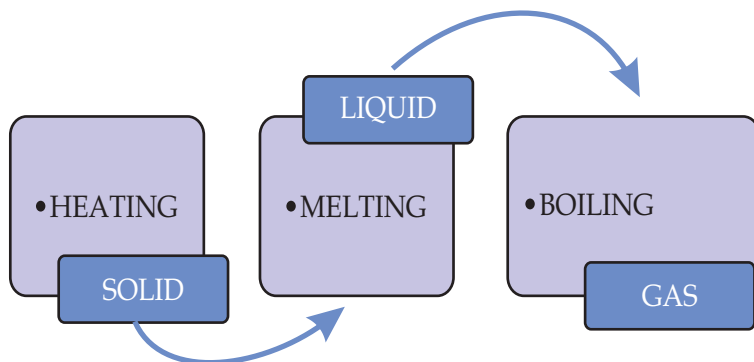



Fig 7.3

When a gas is cooled (Fig 7.4), the molecules move more slowly and collide with one another, may stick together and force of attraction between molecules increases. Keep cooling the gas and eventually all of the molecules stick together to form a liquid. Further cooling will cause all the molecules to stick together to form a solid.

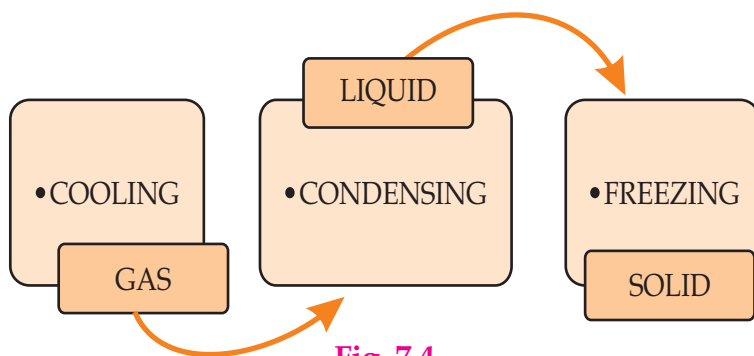
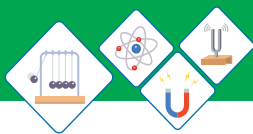



Fig. 7.4

Table 7.2 on the right shows the boiling and melting points of some pure substances:

Helium has lowest boiling and melting points as compared to other substances. It solidifies only when it is cooled and compressed. Mercury is the only metal that is not solid at room temperature.

Table 7.2
Boiling and melting points of some pure substances

Substance	Melting point (°C)	Boiling point (°C)
Helium	-272	-269
Oxygen	-218	-183
Nitrogen	-191	-177
Mercury	-39	257
Water	0	100
Iron	2080	3570
Diamond (Carbon)	4100	5400
Tungsten	3920	6500

Self Assessment Questions:

Q4: Why Tungsten melts at a much higher temperature than iron?

Q5: What is the name of process in which a liquid changes into a solid?

Q6: What is the name of temperature at which a liquid changes into a solid?

Fig 7.5

7.3 GASES AND THE KINETIC THEORY

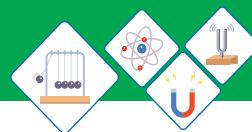
Kinetic molecular theory clearly describes the properties and behavior of gases. Hot air balloons (Fig 7.5)are the practical applications of the discussion given below:

The behavior of gases

The molecules in the gases have relatively large distance between them. The molecules in the gases move about very quickly. A gas molecule moves in a straight line. It changes its direction only when (i) it collides with another gas molecule or (ii) with the walls of its container. After collision it moves away in a new direction .Since gas molecules collide many times each second. Therefore the motion of molecules is constant and random.

The behavior of a gas can be described completely by its pressure, volume and temperature.

Pressure

We already know that pressure is defined as the force per unit area. All the gases exert pressure on the walls of their container. This pressure is the total force exerted per unit area by the gas molecules during collision. The gas molecules exert pressure only when they collide with the walls. The number of collisions is proportional to the number of molecules. If the number

of molecules is doubled then number of collisions will also be doubled (Fig 7.6 a, b, c and d). Hence the pressure is also doubled.

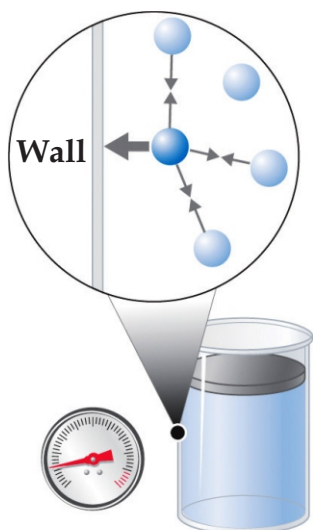



Fig.7.6 (a)
Low pressure

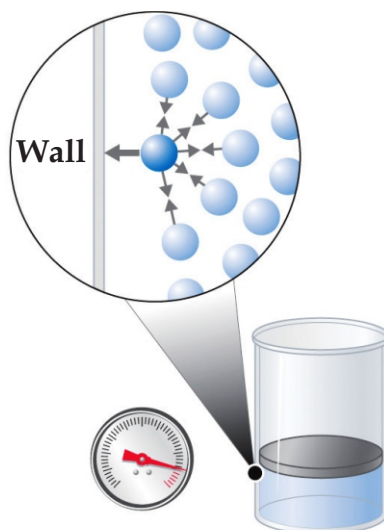



Fig.7.6 (b)
High pressure

Fig.7.6 (c)

Fig.7.6 (d)

of molecules is doubled then number of collisions will also be doubled (Fig 7.6 a, b, c and d). Hence the pressure is also doubled.

Blowing up a balloon is an example of pressure. If more air is pushed into the balloon it will be inflated more. Because air molecules apply pressure on the rubber walls of balloon hence it gets inflated.

Pressure of a gas can also be increased by compressing it. This is done by reducing the size of the gas container (Fig7.7). The gas molecules have been compressed into a smaller volume so they will collide more frequently with the walls of container and creates more pressure. If the gas is compressed to half its original volume its pressure will be doubled.

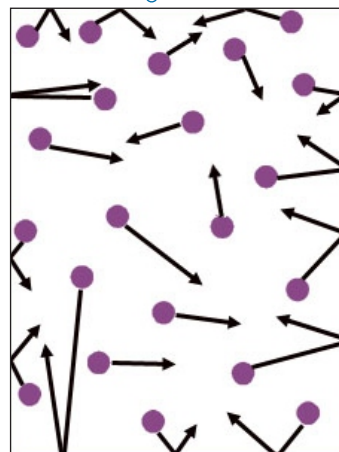
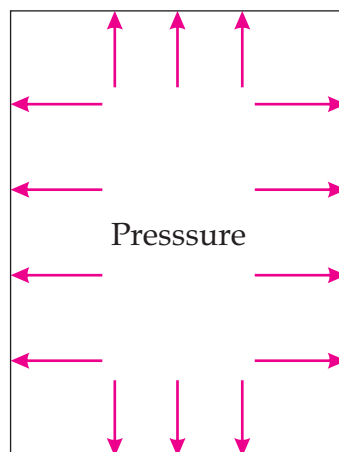
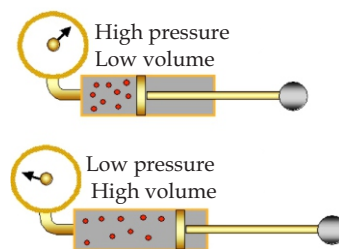
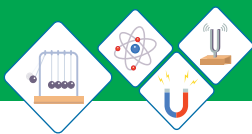



Fig 7.7

Volume

We know that the space occupied by substance is known as volume. The gas has no definite volume because the molecules of the gas are far away from each other and can move freely at high speeds. Therefore gas always takes up the shape and volume of its container.

For example, the smell of a perfume quickly spreads through the room as soon you spray it at your body or clothes. Because, the molecules move freely and randomly at high speeds through out the room. Volume of a gas can also be increased by decreasing its pressure. This could be done by reducing the load on the piston of the gas container. As the gas molecules are in random motion (Fig 7.8) they quickly covers the whole space and the volume increases. If the gas is compressed to half its original volume its pressure will be doubled.

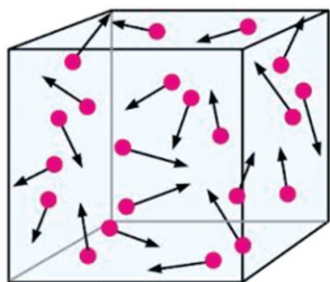



Fig 7.8

Temperature

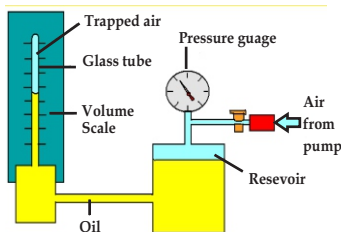
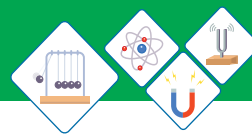
The temperature of a gas is determined by the average translational kinetic energy of its molecules. If a gas is heated the average translational kinetic energy of its molecules increases and temperature of the gas rises. If a gas is cooled down the average translational kinetic energy of its molecules decreases and temperature of the gas falls.

Boyle's Law

Fig 7.9

Pressure - volume relationship in gases

Robert Boyle, an English physicist and chemist in 1662, studied the relationship between pressure and volume of a gas (Fig 7.9) .

The results of a Boyles experiment are shown below:

$$p \propto \frac{1}{V} \text{ or } V \propto \frac{1}{p}$$

1. If pressure of the gas is double its volume becomes half. If pressure increases by three times then volume becomes one-third and so on.
2. The graph (Fig.7.10) between "p" and "V" between "p" and 1/V" are shown below:
3. The graph between "p" and "V" shows that if pressure increases then volume decreases and vice-versa, i.e.
4. The graph between "p" and "1/V" shows a straight line passing through the origin.
5. At constant temperature the product of pressure and volume is constant. i.e.

$$pV = \text{constant} \quad \ldots\ldots\ldots\ldots(7.1)$$

6. Using above result, at constant temperature, we can write Initial pressure x initial volume = Final pressure x final volume

$$p_1 V_1 = p_2 V_2 \quad \ldots\ldots\ldots\ldots(7.2)$$

Thus Robert Boyle conclude his law known as 'Boyle's law' which states that;

The volume of a fixed mass of a gas is inversely proportional to its pressure, provided its temperature remains constant .

Fig 7.10

Applications of (p-V) relationship of a gas "Boyle's law"

Some applications of pressure-volume (p-V) relationship of a gas i.e. Boyle's law are given below in Fig. 7.11(a, b, c):

Fig 7.11 (c)
Applications of Boyle's Law

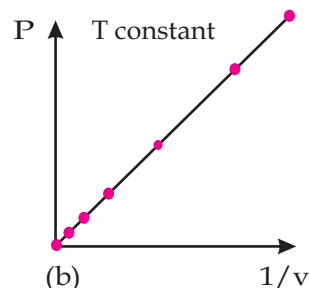
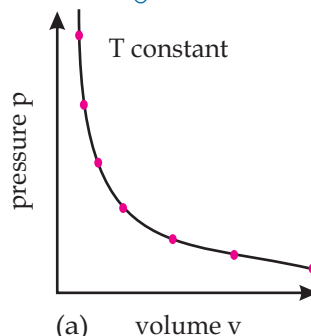
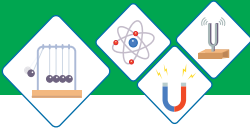
- A bicycle pump is good example of Boyle's law.
- As the volume of the air trapped in the pump is reduced, its pressure goes up, and air is forced into the tyre.

Aerosols, such as spray paints, use the **Boyle's law** in their working mechanism.

Fig 7.11 (a)

Fig 7.11 (b)

Worked Example 1

A cylinder contains $60cm^3$ of air at a pressure of 140kPa. What will its volume be if the pressure on it is increased to 420 kPa?

Solution

Step 1: Write down the known quantities and quantities to be found.

p_1=140kPa
V_1=$60cm^3$
p_2=420kPa
V_2=?

Step 2: Write down the formula and rearrange if necessary.

$$p_1V_1 = p_2V_2 \text{ or}$$

$$V_2 = \frac{p_1 \times V_1}{p_2}$$

Step 3: Put the values and calculate.

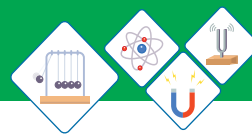
$$V_2 = \frac{140kPa \times 60cm^3}{420kPa} = 20cm^3$$

The new volume is 20 cm^3.

Worked Example 2

Air at a pressure of 1.0×10^5 Pa is contained in a cylinder fitted with a piston. The air is now compressed by pushing the piston, so that the same mass of air now occupies one-fifth the original volume without any change in temperature. Calculate the pressure of the air.

Solution

Step 1: Write down known quantities and quantities to be found.

$p_1 = 1.0 \times 10^5$ Pa

$V_1 = V_1$ cm^3

$V_2 = \frac{1}{5} V_1$ cm^3

Step 2: Write down the formula and re arrange if necessary.

$p_1 V_1 = p_2 V_2$ or

$$p_2 = \frac{p_1 \times V_1}{(1/5)V_1}$$

Step 3: Put the values in formula and calculate.

$$p_2 = \frac{1.0 \times 10^5 \text{ Pa} \times V_1 \text{ cm}^3}{(1/5)V_1 \text{ cm}^3} = 5.0 \times 10^5 \text{Pa}$$

So, the final pressure is now 5.0×10^5Pa.

Do You Know!

An important feature of the equation $p_1V_1 = p_2 V_2$ is that it does not matter what units we use for p and V, as long as we use the same units for both values of p (for example Pa, kPa or atmosphere etc), and the same units for both values of V (for example m^3, dm^3 or cm^3 etc)

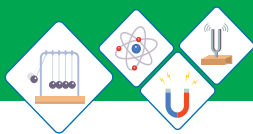
Self Assessment Questions:

Q7: Draw diagrams of the molecules in a gas to explain the effect of pressure change on its volume.

Q8: What is the meant by the subscripts 1 and 2 in the equation, $p_1V_1 = p_2V_2$?

Q9: What is the effect of temperature on average translational kinetic energy of molecules?

Do You Know!

when gas is compressed, volume decreases and the pressure increases.

- Matter exists in three states: solid, liquid and gas.
- The state of a matter can be changed by adding or removing a certain amount of energy .
- The kinetic molecular theory is based upon the arrangement and movement of molecules in a substance.
- The kinetic molecular theory suggests that the molecules in a substance are always in continuous random motion.
- When molecules close to each other, the attractive forces between them become strong .
- The change in force between molecules causes change of state.
- Boyle's law describes the pressure - volume relationship of a gas.
- The pressure and volume of a gas are inversely proportional to each other.'
- Mathematically "$p_1V_1 = p_2V_2$".

Matter

- States of matter
  - Solid
  - Liquid
  - Gas
- Properties
- Molecular motion
  - Brownian Motion

Solid
- Fixed shape
- Fixed Volume
- High Density
- Incompressible
- Minimum Kinetic Energy
- Cannot be poured

Liquid
- No fixed shape
- Fixed Volume
- High Density
- Not easy to compress
- Medium Kinetic energy
- Can be poured

Gas
- No fixed shape
- No fixed Volume
- Low Density
- Easy to compress $\frac{1}{v}$
- Maximum Kinetic energy
- Can be poured

behaviour of a gas

Boyle's Law

Pressure and volume of a gas are inversely proportional to each other

$p \propto \frac{1}{v}$ or

pV = constant or

$p_1V_1 = p_2V_2$

End of Unit Questions

Section (A) Multiple Choice Questions (MCQs)

1. An object with particles close together and vibrating describes a__________.

   a) Gas b) Liquid
   c) Solid d) All three

2. A burning candle is an example of __________ state of matter.

   a) Gas b) Liquid
   c) Solid d) All three

3. During which process a gas becomes a liquid _____.

   a) Melting b) Freezing
   c) Condensing d) Boiling

4. A solid can ______________________ .

   a) have a fixed shape
   b) be easily compressed
   c) take a shape of container
   d) have freely moving molecules

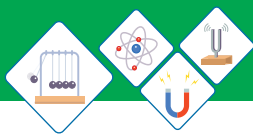
5. According to kinetic molecular theory, the pressure exerted by a gas is caused by the __________.

   a) bombardment of the gas molecules on the walls of the container.
   b) collision between gas molecules.
   c) large distances between gas molecules.
   d) random motion of the gas molecules.

6. If a gas is heated in a sealed cylinder, then________ increases.

   a) pressure inside the container
   b) average kinetic energy of the particles
   c) temperature of the gas
   d) All of them

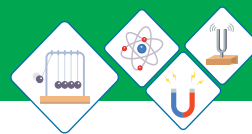
7. A gas in a container of fixed volume is heated. What happens to the molecules of the gas?
   a) They collide less frequently.
   b) They expand.
   c) They move faster.
   d) They move further apart.
8. In a liquid, some energetic molecules break free from the surface even when the liquid is too cold for bubbles to form. What is the name of this process?
   a) boiling b) condensation
   c) convection d) evaporation
9. What happens to the molecules of a gas when the gas changes into a liquid?
   a) They move closer and lose energy.
   b) They move closer and gain energy.
   c) They move apart and lose energy.
   d) They move apart and gain energy
10. A substance has a melting point of –17 °C and a boiling point of 117 °C. In which state does the substance exist at –10 °C and at 110 °C?

	at -10^{0}C	at 110^{0}C
a	Solid	liquid
b	solid	gas
c	liquid	liquid
d	liquid	gas

Section (B) Structured Questions

Kinetic molecular model of matter

1. a) "The particles are free to move within the material, has a fixed volume but takes up the shape of its container", which state of matter is being described here?
   b) Write a similar description of the particles that make up a solid.
   c) Write down any two properties of a solid.
2. a) Why the kinetic model of matter is called kinetic?
   b) In which state of matter the molecules are widely separated?
   c) In which state of matter the molecules are most closely packed?
   d) In which state of matter molecules can move freely at high speed?
3. a) By using kinetic molecular theory explain why we can walk through air, swim through water but can not walk through a solid wall.
   b) In which state of matter do the molecules have minimum kinetic energy?
   c) Which state of matter is highly incompressible?

Forces and Kinetic Theory

4. A sample of a gas is in a sealed test tube is cooled. Describe what happens to:
   a) The size of the molecules.
   b) The speed at which molecules move.
   c) The number of the molecules.
   d) The pressure inside the tube.
   e) The state of the gas.

5. An inflated car tyre is considered to have a constant volume, regardless of any changes in temperature or pressure. Use the kinetic molecular theory of gases to answer the following:
   a) How does air in the tyre exert a pressure on the walls of the tyre?
   b) Why is the pressure the same at all points on the inside wall of the tyre?
   c) More air is pumped into the tyre while the temperature is kept constant until there are twice as many molecules as before. Explain why you would expect the pressure to be doubled.
6. Describe the following:
   a) What happens to the motion of the molecules of a gas when it cools down?
   b) What happens to the motion of a liquid when it cools down?

Gases and Kinetic theory

7. The pressure on $9cm^3$ of oxygen gas is doubled at a fixed temperature. What will its volume become?
8. A container holds $30m^3$ of air at a pressure of 150000Pa. If the volume changed to $10m^3$ by decreasing load on the piston. What will the pressure of the gas become? Assume that its temperature remains constant.
9. Air at atmospheric pressure of 760 mm of Hg is trapped inside a container available with a moveable piston. When the piston is pulled out slowly so that the volume is increased from $100dm^3$ to $150dm^3$, the temperature remaining constant. What will be the pressure of the air becomes?

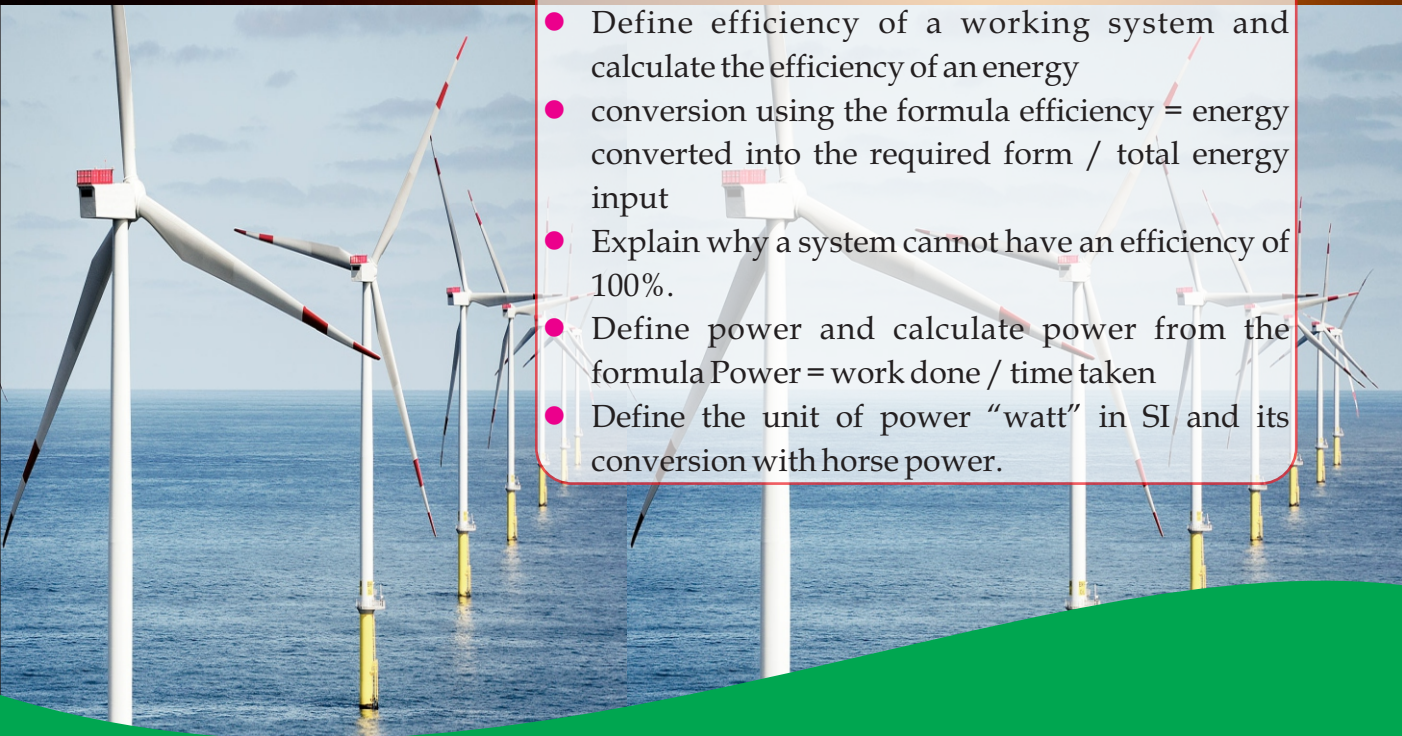
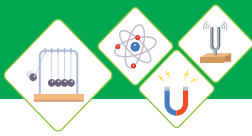
Unit - 8

ENERGY SOURCES AND TRANSFER OF ENERGY

Energy is the most important physical concept which is studied in all sciences. work is closely related with energy which provides a link between force and energy. Work, energy and power have special meaning in physics.

Students Learning Outcomes (SLOs)

After learning this unit students should be able to:

- Define work and its SI unit.
- Calculate work done using equation Work = force × distance moved in the direction of force
- Define kinetic energy and potential energy
- Use Kinetic Energy $E_k = \frac{1}{2} mv^2$ and potential energy $E_p = mgh$; to solve problems.
- Describe the processes by which energy is converted from one form to another with reference to fossil fuel energy, hydroelectric generation, solar energy, nuclear energy, geothermal energy, wind energy, biomass energy and tidal energy.
- Differentiate energy sources as non renewable and renewable energy sources with examples of each.
- Define efficiency of a working system and calculate the efficiency of an energy
- conversion using the formula efficiency = energy converted into the required form / total energy input
- Explain why a system cannot have an efficiency of 100%.
- Define power and calculate power from the formula Power = work done / time taken
- Define the unit of power "watt" in SI and its conversion with horse power.

Force is an agent which tends to change the state of an object.

What source of energy is more beneficent ? Why we face the shortage of petroleum and gas in our country? Why the people are replacing electric energy by solar energy? Why government is focusing its attention on the use of tidal, solar and wind energy? Why the waste material should be buried in Earth? After learning this unit you will be able to answer these questions and some other similar questions.

8.1 WORK

Generally, work refers to perform some task or job. But in physics work has different meaning. For example: A tailor stitching a suit, a shopkeeper selling fruits at his shop, a women cooking in her kitchen are all considered as "doing work" in daily life but in physics work has a proper meaning i.e. "work is done only when a force makes something to move; Fig 8.1(a,b)". Thus work can be define as

The amount of work is the product of force and the distance moved in the direction of force.

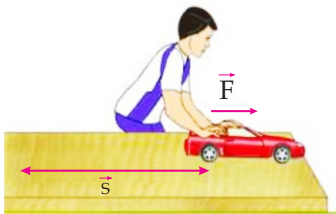



Fig 8.1 (a)
Demonstration of work done

Fig 8.1 (b)
Demonstration of work done

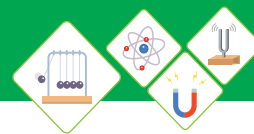
Units of Work

The S.I unit of work is Joule other units of work can be Foot, Pound, Erg.

$$1 \text{ Joule} = 1\text{Nm}$$

Suppose a constant force "F" acts on a body and motion takes place in a straight line in the direction of force then work done is equal to the product of magnitude of force "F" and the distance "d" through which the body moves.

$$W = Fd\cos\theta \quad \text{.........................(8.2)}$$

The force "F" however may not act in the direction of motion of the body instead it makes some angle "θ" with it; Fig 8.2. In that case, we define the

work by the force as the product of the component of the force along the line of motion and the distance "d"; the body moves along that line, i.e.

Suppose a constant force "F" acts on a body

$$\text{Work} = (\text{component of force}) \cdot (\text{distance})$$

$$W = (F\cos\theta)\, d$$

or $$W = (F\cos\theta)\, d$$

If $$\theta = 0 \Rightarrow \cos\theta = 1$$

then $$\text{Work} = W = Fd$$

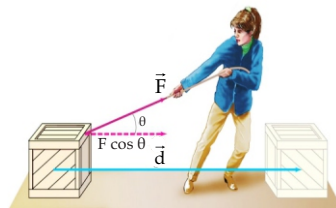



Fig 8.2 (a)
Force making some angle θ with the direction of motion

Fig 8.2 (b)
Force making some angle θ with the direction of motion

Worked Example 1

Find the work done when a force of 50N is applied to move a trolley at a shopping mall through a distance of 200m? Assume the angle to be of 0° between the force and the distance the trolley moved.

Solution

Step 1: Write down known quantities and quantities to be found.

$$F = 50N$$
$$d = 200m$$
$$\theta = 0^\circ$$
$$W = ??$$

Step 2: Write down formula and rearrange if necessary

$$W = F \cdot d$$
$$W = Fd\cos\theta$$

Step 3: Put the values in formula and calculate:

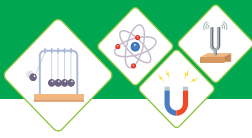
$$W = 50N \times 200m \times \cos 0^\circ$$
$$W = 10000J$$

Hence, the work done is 10000 Joules.

Self Assessment Questions:

Q1: Write down the names of any three units of work

Q2: According to the definition of work in physics, Urwa did not perform any work if she made and assignment on her laptop in three hours. Why?

Q3: At what angle between force and displacement the work done by a body will be maximum?

Energy

Energy is define as

The ability to do work.

the S.I unit of energy is joule (J). There are many forms of energy. Some of them are discussed below:

8.2 Energy Forms

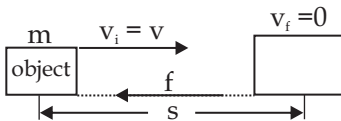
Kinetic Energy

Kinetic energy of a body defined as:

Energy possessed by an object due to its motion is called kinetic energy.

The S.I unit of kinetic energy is joule.

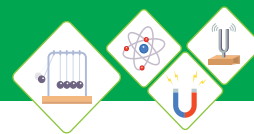
It is also defined as "The work required to accelerate a body of a given mass from rest to its stated velocity". A moving body maintains its kinetic energy unless its speed changes.

Mathematically kinetic energy is given as:

$$\text{K.E} = \frac{1}{2}mv^2 \quad \text{..................(8.3)}$$

As we know that kinetic energy is due to the motion of object. Therefore for an object of mass m moving with speed v kinetic energy depends upon:

- the mass m of the object- the greater the mass, the greater its K.E
- the speed v of the object- the greater the speed, the greater the K.E

Do You Know!

Sailing boat, moving air, driving car, running and walking are example of kinetic Energy.

Worked Example 2

A ball of mass 400 gram, strikes the wall of velocity 4m/sec. How much is the kinetic energy of the ball at the time it strikes the wall?

Solution

Step 1: Write down known quantities and quantities to be found.

$$m = 400\ \text{gram} = \frac{400}{1000}\ \text{kg} = 0.4\ \text{kg}$$

$$v = 4ms^{-1}$$

$$K.E = ?$$

Step 2: Write down formula and rearrange if necessary

$$K.E = \frac{1}{2}\ mv^2$$

Step 3: Put the values in formula and calculate

$$K.E = \frac{1}{2} \times 0.4kg \times (4ms^{-1})^2$$

$$K.E = 3.2J$$

Hence, Kinetic Energy is possessed by the ball 3.2 joules.

Fig 8.4 (a) Gravitational Potential Energy

Potential Energy

Potential energy of a body is defined as:

The energy that a body possesses by virtue of its position, shape or state of a system.

There are different types of potential energy. Like gravitational potential energy, elastic potential energy and chemical potential energy; Fig 8.4 (a, b, c).

For Example:

- A body raised to a height "h" above the ground has gravitational potential energy.
- A stretched spring has elastic potential energy due to its stretched position (condition).

Fig 8.4 (b) Elastic Potential Energy

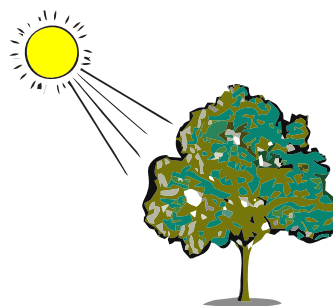
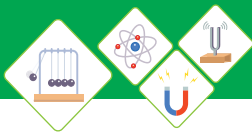



Fig 8.4 (c) Chemical Potential Energy

- The energy stored in the plants that we eat is chemical potential energy.

S.I. unit of potential energy is Joule (**J**).

It is also defined as the work done stored in a body in lifting it to a height "h". The potential energy changes only when its position relative to ground changes; otherwise it remains same.

Mathematically potential energy is given as

P.E = mgh .... (8.4)

Do You Know!

A book lying on the table and the water stored in a dam have potential energies.

Derivation of Gravitational Potential Energy P.E=mgh

To derive the expression for gravitational potential energy, let us consider an object of mass "m" which is raised up through height "h" from the ground; Fig 8.5. The work done in lifting it to height "h" is stored in it as its gravitational potential energy "P.E", i.e.

P.E = Work done	
P.E = W	As W = F.d
P.E = F.d	where d = h (height)
P.E = (mg) . h	F = mg (weight)

Therefore equation becomes:

P.E = mgh .... (8.4)

Fig 8.5
An object of mass 'm' raised to height 'h'.

Worked Example 3

A ball of mass 50 gram is raised to a height of 7m from the ground. Calculate its gravitational potential energy?

Solution

Step 1: Write down known quantities and quantities to be found.

$$m = 50gm = \frac{50}{1000}kg = 0.05kg$$

$$h = 7m$$
$$g = 10ms^{-2}$$
$$P.E = ??$$

Step 2: Write down formula and rearrange if necessary

$$P.E = mgh$$

Step 3: Put values in formula and calculate

$$P.E = 0.05kg \times 10ms^{-2} \times 7m$$
$$P.E = 3.5 \text{ Joule}$$

Hence, gravitational potential energy of the ball is 3.5 Joules.

Self Assessment Questions:

Q4: A car of mass 50kg moving with velocity $10ms^{-1}$ in the direction of force. Calculate its Kinetic energy.

Q5: A body of mass 10kg is dropped from a height of 20m on the ground. What will be its potential energy, if $g=9.8\ m/sec^2$?

Q6: Give the energy changes when a ball is dropped from a height of 7m to the ground.

8.3 CONVERSION OF ENERGY

Energy neither be created nor it can be destroyed but it can be converted from one form to other form. This is called law of conservation of energy.

Conversion of Energy from one form to another

i. Fossil Fuel Energy

Fossil fuel energy is formed from decayed plants and animals that have been converted to crud oil, coal, natural gases or heavy oils by exposure to heat and pressure in the Earth's crust over hundreds of millions of years; Fig 8.6.

Fig 8.6
Fossil fuel energy

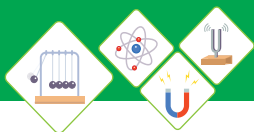



Fig 8.7
Burning charcoal

Fossils fuels have stored chemical energy. This energy is converted by oxidation through burning. Thus on burning a fossil fuel like charcoal, produce heat energy and light energy; Fig 8.7.

ii. Hydroelectric Energy

Fig 8.8
Hydroelectric energy

Hydro electricity is the term referring to electricity generated by hydro power by using gravitational force of falling or flowing water; Fig 8.8.

Most common type of hydro electric power plants uses a dam on a river to store water in a reservoir. Water releases from the reservoir flows through a turbine, spinning it, which in turn runs a generator to produce electricity.

iii. Solar Energy

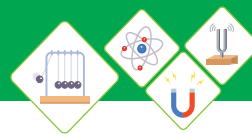
Fig 8.9 (a)
Solar energy (Solar Panel)

The energy radiated from the sun is known as solar energy. This is the most available source of energy throughout Pakistan. There are many devices which are capable of absorbing solar energy, which is then converted into electrical energy or heat energy. These devices may be photovoltaic solar panels and solar cells. Which convert the sun rays into electricity for different uses; Fig 8.9(a). Also solar heaters are used to convert solar energy "sun rays" into heat energy to heat water tanks and indoor spaces; Fig 8.9(b).

Fig 8.9 (b)
Solar energy (Solar heater)

iv. Nuclear Energy

The energy released during a nuclear reaction such as fission or fusion reaction. All radioactive materials store nuclear energy. For example Uranium,

Radium etc. It is released from the nucleus in the form of radiation in addition to heat and light. A nuclear power plant utilize nuclear energy to produce steam to turn a turbine and generate electricity; Fig 8.10.

Fig 8.10
Nuclear energy

v. Geothermal Energy

Geothermal energy is stored in the Earth as its natural heat. Deep in the Earth, there is hot molten part called magma. Water close to magma changes to steam due to high temperature. This thermal energy is conducted to the surface of Earth. This energy is called geothermal energy; Fig 8.11(a).

A geothermal power plant utilizes geothermal energy to drive an electrical generator; Fig 8.11 (b). Geothermal well can be built by drilling deep near hot rocks at different places, where hot molten or magma is very close, water is then pushed down into the well. The rocks quickly heat the water and change it into steam. The steam is used for heating purpose or to generate electricity.

Fig 8.11(a)
Geothermal energy

Fig 8.11(b)
Geothermal power plant

vi. Wind Energy

The energy obtained by the wind is called wind energy. It is generated by wind mills (Fig 8.12). A wind mill consists of a turbine which rotates due to wind. Kinetic energy is produced due to the motion of turbine. Wind turbines convert this kinetic energy into the mechanical power. A generator converts that mechanical power into electricity.

Fig 8.12
Wind energy

Application

- It is being used as source of energy for sailing ships in oceans.
- It is being used by wind mills to pump water.

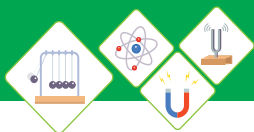



Fig 8.13(a)
Biomass energy (Wood)

Fig 8.13(b)
Biomass energy (Organic materials)

Fig 8.13(c)
Biomass energy (Garbage)

Fig 8.14
Tidal energy

- It is being used by wind mills to grind grain.
- It is used to turn wind turbines to produce electricity.

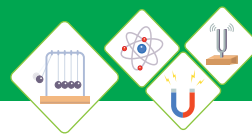
ii. Biomass Energy

Biomass is the organic material that comes from plants and animals. Biomass consists of stored energy from Sun, garbage, wastes, sugarcane etc. Solid biomass, such as wood, organic material and garbage, can be burned directly to produce heat; Fig 8.13 (a, b, c). Biomass can also converted into gas called biogas and into liquid biofuels such as ethanol and biodiesel.

viii. Tidal Energy

It is a form of hydro power that converts the energy obtained from tides into useful form of power; mainly electricity as the Earth uses the gravitational forces of both the moon and the sun every day to move vast quantities of water around the oceans and seas producing tides and in this way energy is produced called tidal energy; Fig 8.14.

Self Assessment Questions:

Q7: What is biomass?

Q8: Write down the name of fossil fuel?

Q9: Which type of energy is stored deep in the Earth?

8.4 RENEWABLE AND NON-RENEWABLE ENERGY SOURCE

Renewable Energy Source

The renewable sources can be consumed and used again and again. Solar energy, wind energy, tidal energy and geothermal energy are renewable sources.

Since very earlier age, people have tried to consume renewable sources of energy for their survival. Such as wind and water for milling grain and solar for lighting.

Non-Renewable Sources

Non-renewable resources are limited and will finish once used. Coal, petroleum and natural gases are nonrenewable sources. About 150 years ago scientists invented new technology to extract energy from the ancient fossilized remains of plants and animals. These super-rich but limited sources of energy (coal, oil and natural gas) replaced wood, wind and water as the main sources of fuel. They are being used at a faster rate than they can be restored again and, therefore cannot be renewed.

Self Assessment Questions:

Q10: Write down the names of any three renewable energy sources?

Q11: Write down the names of any three non-renewable energy sources.

Q12: What is the difference between renewable and non-renewable energy sources?

Do You Know!

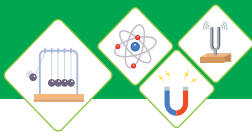
- Wind energy is clean fuel source.
- It does not pollute the air.
- Wind turbines does not produce atmospheric emission that causes greenhouse gasses.

8.5 EFFICIENCY

Every machine needs some energy to perform work. Whatever energy given to a machine is called input and the work done by the machine is called output.

For example: We give electric energy as input to the electric motor in washing machines and in drilling machines.

Do You Know!

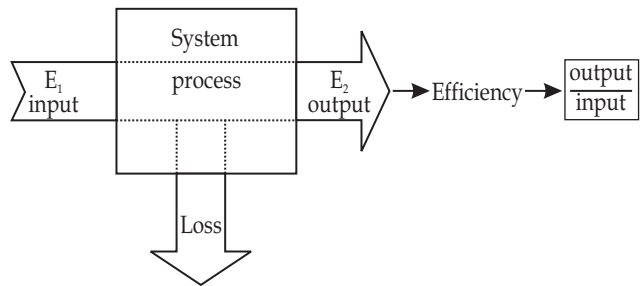
The costal belt of Pakistan is about 1045 km long with best resources for utilizing and producing tidal energy.

A system in which some energy 'E_1' is supplied to it as 'input' and the system returns back some energy 'E_2' as output has some efficiency. This efficiency is defined as

The ratio of output to the input is called Efficiency.

Efficiency is denoted by "η". As it is the ratio of two energies therefore it has no unit. No machine is 100% efficient because some energy is always wasted in the form of heat, sound or light etc.

$$\text{Efficiency} = \frac{\text{Energy as output}(E_2)}{\text{Energy as input}(E_1)}$$

$$\therefore \qquad \eta = \frac{E_2}{E_1} \times 100$$

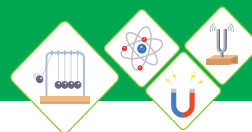
$$\text{Efficiency} = \frac{\text{output}}{\text{input}} \times 100 \quad \text{.........................(8.5)}$$

8.6 POWER

When you run up and cover distance in 5 seconds or take slow walk up the same distance in 20 seconds. You are doing the same amount of work, However, you are doing it at different rate. When you run up, you are working much faster and you have a higher power then when you walk up.

This quantity that tells us the rate of doing work. Thus, power is defined as:

Do You Know!

We get

- Chemical energy from fuel, gas and battery
- Thermal energy from heat
- Nuclear energy from nuclear Fission and fusion
- Electrical energy from movement of electrons in atom
- Mechanical energy from walking, running
- Sound energy from sound waves

The rate of doing work. or
The amount of energy transferred per unit time.

Mathematically,

$$\text{Power} = P = \frac{\text{work done}}{\text{time taken}}$$

$$\therefore \quad P = \frac{w}{t} \quad \text{.......................(8.6)}$$

Since work and time are scalar quantities. Therefore, power is also a scalar quantity.

Unit of Power

In SI system unit of power is $\frac{\text{Joule}}{\text{sec}}$ = Watt

Thus SI unit of power is watt which is defined as:

The power of a body is said to be one watt if it does work at the rate of one Joule per second.

Worked Example 5

Calculate the power of a machine. If the machine performs 900 joules of work in 30 minutes.

Solution

Step 1: Write down known quantities and quantities to be found.

$$W = 900J$$

$$t = 30min = 30 \times 60s = 1800\,s$$

$$P = ??$$

Step 2: Write down formula and rearrange if necessary

$$P = \frac{W}{t}$$

Step 3: Put values in formula and calculate

$$P = \frac{900J}{1800s}$$

$$P = 0.5\,W$$

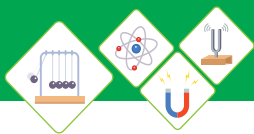
Hence, power of the machine is 0.5 Watt.

Do You Know!

1kg of 4% enriched fuel grade uranium releases energy equivalent to the combustion of nearly 100 tons of high grade coal or 60 tons of oil.

Do You Know!

Larger units of power are

Kilo watt (kW),
Mega watt (MW),
Horse Power (hp) etc.
$1kW = 1000W = 10^3$ watt
$1MW = 1000000W = 10^6$ Watt
1 hp = 746 Watt

Self Assessment Questions:

Q13: A man pushes a car 18m with a force of 2N in 4 second. Calculate the power of the man.

Q14: Why power is a scalar quantity?

Q15: Name the physical quantity which gives the rate of doing work.

- Work is the product of force and the distance W= F·S
- The ability to do work is called energy. SI unit of energy is Joule (J).
- Energy possessed by an object due to its motion is called as Kinetic Energy $K{\cdot}E = 1/2\,mv^2$
- Energy due to position of an object is called Potential Energy P·E=mgh.
- Energy exists in many different forms such as nuclear energy, heat energy, electrical energy, chemical energy, light energy, etc.
- Solar energy, wind energy, tidal energy, geothermal energy, biomass energy and hydroelectric energy are the examples of renewable sources of energy.
- Wood, coal, petroleum, natural gas and Uranium are examples of nonrenewable sources of energy.
- The ratio of output to the input is called efficiency.
- The work done in unit time is called power. SI unit of work is Watt.

CONCEPT MAP

Energy

Forms Of Energy

- Kinetic energy $K.E = 1/2\ mv^2$
- Potential energy $P.E = mgh$
- Fossil Fuel energy
- Hydroelectric energy
- Nuclear energy
- Geothermal energy
- Wind energy
- Biomass energy
- Tidal energy
- Heat energy
- Electrical energy
- Chemical energy
- Solar energy

Energy Sources

- Renewable energy
  - Biomass energy
  - Hydroelectric energy
  - Solar energy
  - Wind energy
  - Tidal energy
  - Geothermal energy
- Non-renewable energy
  - Fossil fuel energy
    - Petroleum
    - Wood
    - Coal
    - Natural gas
  - Nuclear energy
    - Uranium

Law Of Conservation Of Energy

Transfer Of Energy

- Use to perform → Work $W = F \cdot d$
- Rate at which energy transfers → Power $P = \frac{W}{t}$
- Ability to transform → Efficiency $\eta = \frac{E_2}{E_1} \times 100$

End of Unit Questions

Section (A) Multiple Choice Questions (MCQs)

1. If force of 6N displaces an object 2m in the direction of force, then work done will be__________.
   - a) 0 b) 12 Joule
   - c) 3 Joule d) Both b and c
2. If a body of mass 1 kg is moving with velocity of 1m/sec then K.E of the body will be ____________.
   - a) Joules b) Joules
   - c) Joules d) 1 Joule
3. If a machine performs 20J of work in 10sec then its power is ________.
   - a) 200 watt b) 20 watt
   - c. 2watt d) 0.2 watt
4. A body of mass 1kg is lifted through a height of 1m . The energy possessed in the body will be_______. (consider $g = 10ms^{-2}$)
   - a) 1J b) 10 Joule
   - c) 100 Joule d) 1000 Joule
5. The energy released during fission or fusion reaction is called ____________.
   - a) Solar energy b) Geothermal energy
   - c) Tidal energy d) Nuclear energy
6. Which is the renewable source of energy
   - a) Solar and wind b) Coal
   - c) Natural gas d) Petrolium
7. The ratio of output to input is called
   - a) Energy b) Work
   - c) Power d) Efficiency

8. Work done per unit time is called __________.

   a) Efficiency b) Energy
   c) Power d) Force

9. Coal, gas and oil are all examples of_________.

   a) Tidal energy b) Nuclear energy
   c) Fossil fuel energy d) Biomass energy

10. ____________ is not a renewable source of energy.

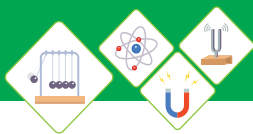
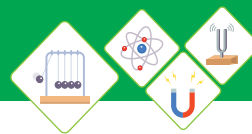
   a) Solar energy b) Coal
   c) Wind energy d) Geothermal energy

Section (B) Structured Questions

Work

1. a) Define work?
   b) Derive the equation; work = Fd cosθ.
2. How much work is needed to move horizontally a body 20m by a force of 30N, the angle between the body and the horizontal surface is 60^{o}?
3. How much work is done, if a crate is moved at a distance of 50m, when a force of 30N is applied along the surface.
4. What is the work done by Usman? If a bar of weight 100 N is brought by him from A to B, then brought back to A.

Energy Forms

5. a) Define Kinetic energy
   b) Derive the equation.
6. What will be the Kinetic energy of a boy of mass 50kg driving a bike with velocity of $2ms^{-1}$.
7. a) Define Potential Energy
   b) Derive the equation. PE = mgh

8. a) If LED screen of mass 10kg is lifted up and kept it on a cupboard of height 2m. Calculate the potential energy stored in the LED screen.
   b) Calculate the potential energy of 3kg water raised to the tank at the roof of a home 4m high. (assume $g=10ms^{-2}$)

Conversion of Energy

9. a) Why fossil fuel energy is called non-renewable source?
   b) Define solar energy and its importance in Pakistan?
10. Write notes on Tidal energy and Geothermal energy.
11. a) What is wing energy?
    b) Write any three applications of wind energy ?
12. a) Write the name of any one radioactive element which is used as source of nuclear energy.
    b) Write the names of any one device that can convert solar energy into heat energy.
    c) Write the names of any two devices that can convert solar energy into electrical energy.

Renewable and Non-renewable Energy Sources

13. Write a note on renewable energy sources?
14. Write a note on non-renewable energy sources?
15. What is the difference between renewable of non-renewable energy sources?
16. Make a table of renewable and non-renewable energy sources from the following:

    Uranium, Solar, Coal, Wind, Natural gas, Tidal, Biomass, Hydroelectricity.

Efficiency

17. Calculate the efficiency of a machine which consumes 200 J of energy and performs 50J of work.
18. Write a note on efficiency.
19. If the efficiency of a machine is 70% and its output is 100 J then calculate its input.
20. Which machine is more efficient, machine "A" which has an output of 200J after consuming 400J of energy or machine "B" which has an output of 300J after consuming 450J of energy?

Power

21. a) Define power.
    b) The energy of 600J dissipated by a bulb in 50 minutes. Find the power of the bulb.
22. a) Convert 20watt into horse power.
    b) Calculate the power of a machine, if it does 40 Joules of work in 10 sec.
23. a) Define Watt.
    b) A student of weight 400N takes 5 sec to climb up an obstacle of height 2m. Calculate the power consumed ?
24. a) Write down the names of any two larger units of power.
    b) If a machine consumes 250J of energy per hour then what will be its power?

Unit - 9

THERMAL PROPERTIES OF MATTER

The properties of matter which change with the change in temperature are called "Thermal properties". Materials change their states due to change in their temperature, cause by the addition or removal of heat. Like for example, water changes from liquid to gas 'steam' due to addition of heat or to solid 'ice' due to removal of heat. The process of evaporation, boiling, freezing, thermal expansion (liner and volumetric) are all happens due to the change in temperature of the substance. Thus changes in temperature caused by the addition or removal of heat play very important role in our daily life.

Students Learning Outcomes (SLOs)

After learning this unit students should be able to:

- Differentiate between heat and temperature
- Define the terms heat capacity and specific heat capacity with SI unit
- Describe one everyday effect due to relatively large specific heat of water
- Describe heat of fusion and heat of vaporization (as energy transfer without a change of temperature for change of state)
- Describe experiments to determine heat of fusion and heat of vaporization of ice and water respectively by sketching temperature-time graph on heating ice.
- Explain the process of evaporation and the difference between boiling and evaporation.
- Explain that evaporation causes cooling
- List the factors which influence surface evaporation
- Define thermal expansion
- Describe qualitatively the thermal expansion of solids (linear and volumetric expansion)
- List and explain some of the everyday applications and consequences of thermal expansion
- Explain the thermal expansion of liquids (real and apparent expansion)

The objective of this unit is to create critical logical thinking among the students, so that they can observe and analyze the physical quantities and changes taking place in their surroundings.

- How does water in our surrounding helps us to maintain the temperature of environment?
- Why different liquids heat up in different manner at same time an same temperature?
- What is the importance of specific heat in everyday life?
- How evaporation takes place and its affects on the surroundings?
- What happen when temperature of solids and liquids increases?
- How does physical state of matter changes from one state to other?
- Why wet clothes take more time to dry out in cloudy day?
- What is the role of thermal expansion in our daily life?

Do You Know!

Heat transfers in three ways
i. Conduction
ii. Convection
iii. Radiation

9.1 HEAT AND TEMPERATURE

Heat

Mostly we think that heat and temperature are the same, however, this is not true, they are related with each other, but are different concepts; Fig 9.1(a, b).
Heat is a form of energgy. Where as temperature is flow of heat.
For Example: A hot cup of tea is placed on table, after some time the tea in the cup becomes cold because surrounding temperature is lower than that of the hot tea. Hence heat flows from hot cup to the surrounding. Therefore heat and temperature can be stated as:

Fig 9.1 (a)
Heat

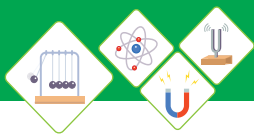
Fig 9.1 (b)
Temperature

Heat	Temperature
It is the form of energy which transfers from hot body to cold body as a result of difference of temperature between them. As heat is form of energy. Therefore its SI unit is joule. Its other unit is calorie.	It is a degree of hotness of a body. It determines the direction of flow of heat from one body to the other body. SI unit of temperature is Kelvin. Its other units are Celsius and Fahrenheit.

Thermometer

Thermometer is a device, used to measure temperature.
For example;
A clinical thermometer is used to measure the temperature of human body (Fig 9.2).

Fig 9.2
Clinical thermometer

Thermometers have different scales to measure temperature.

There are three scales of temperature (Fig 9.3).

1. Celsius scale (Mostly used for environmental measurements)
2. Fahrenheit scale (Mostly used for clinical measurements)
3. Kelvin scale (Mostly used for industrial measurements)

These three scales of temperature are interconvertible. Therefore temperature measured in Celsius scale can be converted into Kelvin and Fahrenheit scales as follows:

Conversion of temperature from Celsius scale to Kelvin scale

$$K = {}^{\circ}C + 273$$

Conversion of temperature from Celsius scale to Fahrenheit scale

$$^{\circ}F = 1.8^{\circ}C + 32$$

Do You Know!

The temperature of a small cup of tea might be the same as the temperature of a large cup of tea , but the large cup of tea gas more amount of heat because it has more tea has amount of thus more total thermal energy.

Do You Know!

Specific heat of water is 4200 $Jkg^{-1}K^{-1}$.
Boiling point of water is 100°C

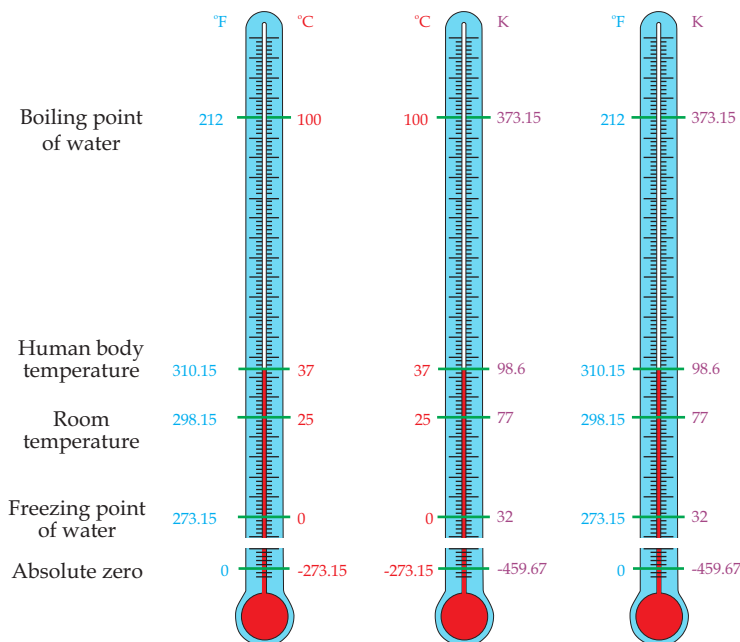



Fig 9.3
The three scales of thermometer

Worked Example 1

The temperature of Hyderabad on a hot day is 45 degree Celsius (45°C). What will be its equivalent temperature on Fahrenheit Scale?

Step 1: Write down known quantities and quantities to be found.

$$°C = 45°$$
$$°F = ??$$

Step 2: Write down formula and rearrange if necessary

$°F = 1.8°C + 32$

Step 3: Put values in formula and calculate

$°F = 1.8 \times 45 + 32$

$°F = 113°$

Hence, the equivalent temperature in Fahrenheit scale is 113°F.

Self Assessment Questions:

Q1: Differentiate between heat and temperature.

Q2: Why we can not tell temperature of a body by teaching it?

Q3: Explain different scales used in thermometers to measure the temperature

9.2 SPECIFIC HEAT CAPACITY

Heat Capacity

Heat capacity is a term in physics that describe how much heat is added to a substance to raise its temperature by 1°C.

Mathematically $C = \frac{Q}{\Delta T}$ where Q = amount of heat absorbed and ΔT is change in temperature.

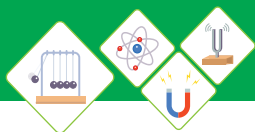
Heat capacity depends upon the nature of material. For example Two beakers contain equal masses of water and oil are heated by the same gas burner for three

Substance	Specific heat capacity (J/(kg·°C))
Water	4.18×10^3
Ethyl alcohol	2.46×10^3
Ice	2.1×10^3
Aluminum	9.2×10^2
Glass	8.4×10^2
Iron	4.5×10^2
Copper	3.8×10^2
Sliver	2.4×10^2
Lead	1.3×10^2

Table 9.1
Specific Heat Capacity of different substances.

minutes. Then it is observed that the temperature of oil may rise twice than water.

Specific Heat Capacity

When comparing the heat capacity of different substances, we are actually talking about their specific heat capacity.

Hence specific heat capacity can be defined as:

Amount of heat required to raise the temperature of 1 kg of a substance through 1 °C is called specific heat capacity of that substance.

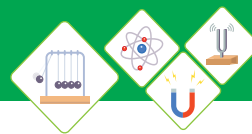
Equation of specific heat capacity 'c' is as under:

$$c = \frac{C}{m} = \frac{1}{m}\left(\frac{Q}{\Delta T}\right)$$

$$c = \frac{\Delta Q}{m\Delta T} \quad \text{...............(9.1)}$$

Where "c" is constant which depends upon the nature of material of the body. This constant is called as specific heat capacity or specific heat. Its SI unit is joule per kilogram per Kelvin (**$Jkg^{-1}K^{-1}$**).

Table 9.1 shows the specific heat capacity of different substances of common use.

Effects due to large specific heat of water

We know that water has a large specific heat, due to this quality it plays an important role in everyday life.

- The large amount of water in oceans and lakes help to maintain the temperature ranges in their surroundings.
- Water with coolant is used to reduce the temperature of engine through radiator of vehicle.
- Water also help to maintain our body temperature.

Do You Know!

Water has very high specific heat, while the sand has relatively low specific heat, therefore the sand heats up very quickly with little energy.

Worked Example 2

The thermal energy required to raise the temperature of 50g of water from 40°C to 70°C is 6300 Joules. Calculate the specific heat capacity of water.

Step 1: Write down known quantities and quantities to be found.

$T_1 = 40°C$

$T_2 = 70°C$

$\Delta T = T_2 - T_1 = 70°C - 40°C = 30°C = 30K$

$\Delta Q = 6300J$

$m = 50g = 0.05\,kg$

$c = ?$

Step 2: Write down formula and rearrange if necessary

$$c = \frac{\Delta Q}{m\Delta T}$$

Step 3: Put values in formula and calculate

$$c = \frac{6300J}{0.05kg \times 30K}$$

$$c = 4200Jkg^{-1}K^{-1}$$

Hence, specific heat of water is $c = 4200Jkg^{-1}K^{-1}$.

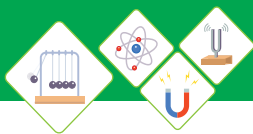
Do You Know!

Soil has specific heat capacity of 810 $Jkg^{-1}K^{-1}$, which is about 5 times less than that of water.

Self Assessment Questions:

Q4: Define specific heat capacity.

Q5: Write down the factors on which specific heat capacity depends.

Q6: Write examples of specific heat capacity from daily life experience.

9.3 Heat of fusion and heat of vaporization

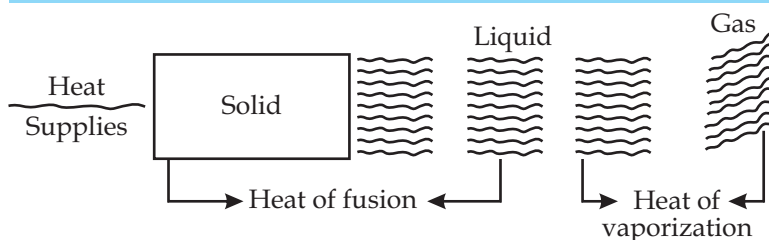
Heat of fusion

The heat absorbed by a unit mass of a solid at its melting point in order to convert solid into liquid without change of temperature is called "heat of fusion".

Heat of vaporization

When a beaker filled with water placed on a burner to boil, the temperature of water gradually raises until it reaches 100°C. At this temperature it starts to boil, that is to say that bubbles of vapor formed at the bottom and start to raise to the surface and then escape in the form of steam. At this stage the temperature of water (liquid) and of water vapors (gas) is same. Thus the heat energy which is required to convert water from liquid to vapor state is know as "heat of vaporization". Therefore heat of vaporization is defined as:

The amount of heat energy required to change the state of a substance from liquid to vapor form, without changing its temperature is called "heat of vaporization".

- The heat of fusion for water at 0°C is approximately 334 Joules per gram.
- The heat of vaporization for water at 100°C is about 2230 Joules per gram.

Activity

Encourage students to take solid ice pieces in a container and supply heat through burner, and observe the process of heat of fusion in class/lab.

Experiments given below determine latent heat of fusion and latent heat of vaporization of ice and water respectively by sketching temperature-time graph of heating ice. This experiment has two parts

(i) Conversion of ice into water.

(ii) Conversion of water into steam.

(i) Convert Ice (Solid) into Water liquid

Experiment

Take a container and place it on a stand as shown in; Fig 9.4. Put small pieces of ice in the container. Suspend a thermometer in the container to measure the temperature. Take a stop watch to measure accurate time at different stages. Now place the container on the burner. The ice will start melting after absorbing heat. The temperature will remain same up to 0°C until all the ice melts. Note the time t_1 and t_2, which the ice takes to melt completely into water at 0°C. Supply heat continuously to water at 0°C, again note the time, Its temperature will start to increase. Note the time, which water in container takes to reach its boiling point at 100°C from 0°C. Draw a temperature-time graph as shown in graph 9.1. Calculate the heat of fusion of ice from the data using the graph.

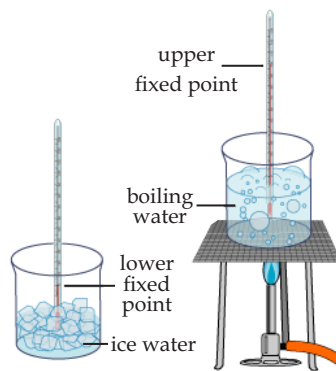
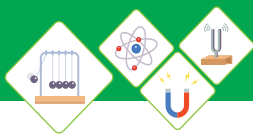
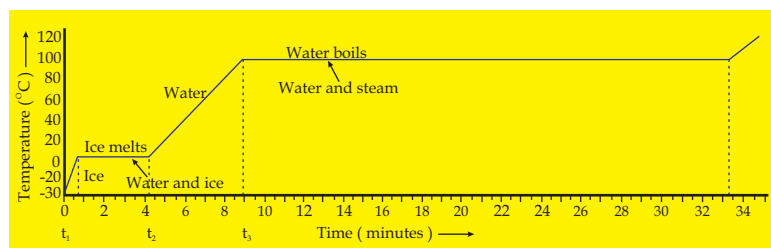



Fig 9.4
Heating ice experiment

Graph 9.1. Temperature-time graph of heating ice

Experiment

(ii)Convert Water (Liquid) into steam (Gas)

It is continuity of previous experiment; Fig 9.5. The container now contains boiling water we continue to supply heat to water, till all the water convert into steam. Note the time during which water in container completely changed into steam at its boiling point, using the temperature-time graph no 9.1 calculate the heat of vaporization of water.

Table 9.2 shows heat of fusion and vaporization of different elements.

Self Assessment Questions:

Q7: Why does the temperature not increase when ice is heated at 0°C ?

Q8: Why does the temperature not increase when water is heated at 100 °C? Explain.

9.4 EVAPORATION PROCESS

It is our common observation that wet clothes dry in sun due to the evaporation. The water in the wet cloth takes heat energy from sun and get evaporated. Similarly the water taken from the sea is kept under the sun for a long period of time leading to the evaporation of the water molecules and as a result the common salt is formed, which is left as remnants in this whole process. We mostly notice that water placed in a pot, disappear slowly. It is because of evaporation process

The process in which the water changes from liquid to gas or vapor form is known as "evaporation".

Difference between boiling point and evaporation

Evaporation	Boiling
1. It takes place without supply having external heat source.	1. It only takes place without on supply external heat source.
2. It occurs at any temperature below boiling point.	2. It occurs only at certain temperature called "Boiling point".
3. It causes cooling.	3. It do not causes cooling.
4. It is relatively slow.	4. It is relatively fast.
5. It takes place only at the liquid surface.	5. It takes place throughout the liquid.
6. No formation of bubbles.	6. Bubbles are formed.

Figure 9.5 demonstrates the difference between evaporation and boiling. The table 9.3; shows the freezing and boiling points of some important solvents.

Fig 9.5
Difference between evaporation and boiling

Solvent	Freezing point (°C)	Boiling Point (°C)
Water	0.0	100
Acetic acid	17.0	118.1
Benzene	5.5	80.2
Chloroform	-63.5	61.2
Ethanol	-114.7	78.4

Table 9.3 Freezing and boiling points of different solvents

Evaporation causes cooling

When evaporation occurs, the molecules of water with greater Kinetic energy escape from its surface. So the molecules of water with lower Kinetic energy are left behind. This results in a decrease in the temperature of water. Hence, evaporation causes cooling.

You feel cold when come out directly under a heavy wind after taking bath. This is due to the reason

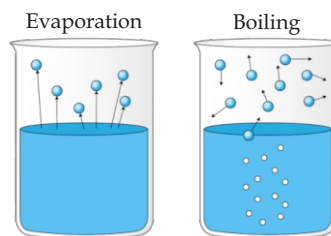
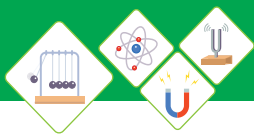



Fig 9.6
Evaporation causes cooling

that water molecules with greater Kinetic energy escape from your skin surface, while the molecules with lower Kinetic energy are left behind. This lowers the temperature of water at your skin and you feel cold.

Some liquids have low boiling point due to which they change from liquid to vapor very easily at ordinary temperature, these liquids are called 'volatile liquids'.

For Example methylated ether has low boiling point. If little amount of methylated spirit is taken on our hand it evaporates rapidly and our hand feel instantly cold. To change spirit from liquid to vapor it requires latent heat which is obtained from our hand thus our hand losses heat and we feel cool.

Water also causes the hand to become cold but it is not felt as spirit. The water has high boiling point then spirit so it evaporates slowly at the temperature of our hand and hence it does not cause the cooling effect.

Factors which Influencing Surface Evaporation

a. **Temperature:** With the increase in temperature the rate of evaporation also increases.

b. **Wind Speed:** Rate of evaporation also increases with the increase in wind speed.

c. **Surface area of liquid:** Rate of evaporation increases with the increase in surface area of liquid.

d. **Humidity:** The rate of evaporation decreases with increase in humidity.

e. **Nature of liquid:** Nature of liquid also effect the rate of evaporation. Liquid with lower boiling point have grater vapor pressure and evaporate more rapidly.

f. **Solute Concentration:** Salty water evaporates more slowly than pure water.

Self Assessment Questions:

Q9: Define evaporation and factors influencing evaporation process.

Q10: Differentiate between boiling and evaporation.

Q11: What is the freezing point of ethanol in Celsius scale?

9.5 THERMAL EXPANSION

Most solid materials expand on heating and squeeze on cooling because on heating the kinetic energy of their molecules increases. Therefore changes take place in shape, area and volume of the substances with the change in temperature. This is called "thermal expansion", defined as:

The expansion of substance on heating is called thermal expansion.

Fig 9.7 (a)
Thermal expansion

Examples of thermal expansion

- Expansion in railway tracks in summer; Fig 9.7(a).
- Expansion in electric wires in summer; Fig 9.7(b).
- Expansion in bridges in summer; Fig 9.7(c), etc.

Fig 9.7 (b)
Thermal expansion

Expansion of Solid

The molecules of solid materials vibrate at their mean positions. So, when a solid is heated, its molecules vibrate with greater amplitudes due to increase in their kinetic energy. As a result the solid expands its length and volume.

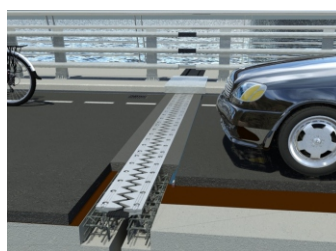



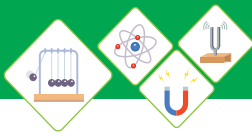
Fig 9.7 (c)
Thermal expansion

Linear Expansion

Fig 9.8
Linear expansion

The expansion in length of a solid object on heating is called linear expansion.

It is one dimensional expansion as it occurs only along the length of the object; Fig 9.8.

Suppose a rod of some material with original length L, at initial temperature T, is heated through a certain temperature T′, then its length increase and becomes L′.

Therefore

Change in temperature $= \Delta T = T' - T$ -------(i)

Change in length $= \Delta L = L' - L$ ---------------(ii)

It has been experimentally proved that change in length is directly proportional to the original length and change in temperature. Therefore

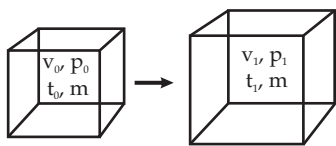
$\Delta L =$ (constant) $L \Delta T$ -----------------------(iii)

This constant is denoted by α, and is called coefficient of linear expansion. It depends upon the nature of the material.

Therefore equation (iii) can be written as

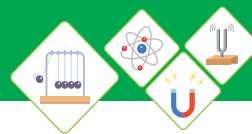
$$\Delta L = \alpha L \Delta T \text{---------------------(9.2)}$$

Do You Know!

The co-efficient of volume expansion of liquids greater than solids.

Volumetric Expansion

The expansion in volume of a solid object on heating is called volume expansion.

Fig 9.9
Volumetric expansion

It is three dimensional expansion as it occurs along the length, width and height of the object (Fig 9.9). Consider a solid body having volume V, at some initial temperature T. When the body is heated its temperature changes from T to T′ and its volume becomes V′.

Therefore

Change in temperature = $\Delta T = T' - T$ -------(i)

Change in volume = $\Delta V = V' - V$ ----------- (ii)

It has been experimentally proved that change in volume is directly proportional to the original volume and change in temperature.

ΔV = (constant) $V \Delta T$ ---------(iii)

This constant is denoted by "β" and is called coefficient of volume expansion. It depends upon the nature of material.

Therefore equation (iii) can be written as:

$$\Delta V = \beta V \Delta T \quad .... (9.3)$$

NOTE:

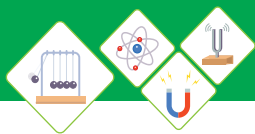
As linear expansion occurs in one dimension, where as volume expansion occurs in three dimensions. Hence, coefficient of volume expansion "β" is three times than coefficient of linear expansion "α":

Therefore:

$$\beta = 3\alpha \quad ....(9.4)$$

Substance	Coefficient of expansion per degree centigrade
Aluminum	25×10^{-6}
Brass or Bronze	19×10^{-6}
Brick	9×10^{-6}
Copper	17×10^{-6}
Glass (Plate)	9×10^{-6}
Glass (Pyrex)	3×10^{-6}
Ice	51×10^{-6}
Iron or Steel	11×10^{-6}
Lead	29×10^{-6}
Quartz	0.4×10^{-6}
Silver	19×10^{-6}

Table 9.4

The coefficients of linear expansion of different substances.

Application and Consequences of thermal expansion

Thermal expansion of solids is useful in some situations of daily life and in some situations it creates problems:

Fig 9.10
Bimetalic Thermostat

Applications

Bimetal thermostat

Bimetallic thermostat (Fig.9.10) is used to control temperature of ovens, irons water heaters, refrigerators, air conditioners and so on. It is designed to bend when it becomes hot. Two metals with different coefficient of linear expansion are joined firmly to make it . When it is heated, metal with large value of coefficient of linear expansion more than the other, causing the strip to bend. In this way, it cuts off the current supply. The current supply to the circuit is restored again when it cools down.

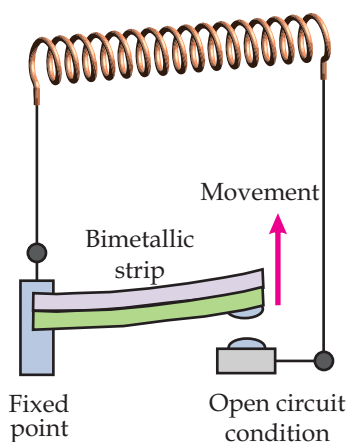



Fig 9.11 Rivet

Rivets

Rivets(Fig.9.11) are used in shipbuilding and other industries to join metal plates. A red-hot rivet is passed through holes in two metal plates and hammered until ends are rounded. The rivet contracts on cooling and pulls the two plates tightly together.
A metal rim can be fixed on a wooden wheel(Fig.9.12) of a bull cart. The diameter of metal rim is set little bit smaller than the diameter of wooden wheel. The diameter of metal rim increases on heating and can easily be put over the wooden wheel. It contracts on cooling and holds wooden wheel tightly.

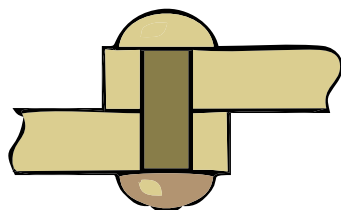
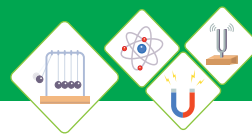



Fig 9.12
Wooden Wheel

i. Car Radiator Coolant

Engine coolant is used in car radiator in place of pure water because water has greater volume expansion it can expand enough to damage the engine or radiator.

ii. Mercury in Thermometer

Mercury expands on heating and contracts on cooling. It do not stick to the walls of thermometer. Therefore Mercury is placed in long sealed capillary tube in thermometer. Change in the temperature is measured by the position of mercury in capillary tube which has calibrated marks with °F, °C or K scale.

iv. Rail Tracks

The rail tracks are made up of metals and hence they expand in summer due to hot weather. Hence, small gaps are left at the joints of sections of tracks; Fig 9.13. This allows the tracks to expand safely. If these gaps are not left between the tracks, the tracks buckled and train would be de-tracked (derailed).

Fig 9.13
Gaps between Rail Tracks

Real and Apparent expansion of liquids

Consider a flask, filled with water up to level "a". The flask is placed on a burner, as shown below in; Fig 9.14.

Heat start to flow through the flask to water. So, the flask expand first. Due to expansion of flask, the level of water falls from point "a", level L_1 to point "b", level L_2. So, when water get heated, it start to expand from a point "b" beyond its original level.

Thus expansion of water appear from level "L_1" point "a" to level "L_3" point "c" is called "apparent expansion of water". But in real sense, the water on heating has expanded from level "L_2" point "b" to level "L_3" point "c" which is the "real expansion of water".

Real expansion = L_2 to L_3 i.e from point "b" to "c", as shown in; Fig 9.14.

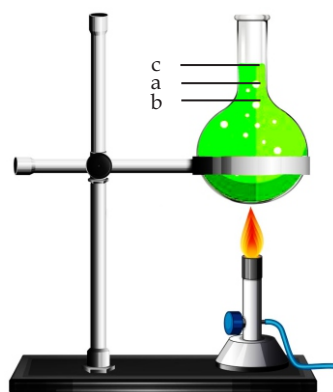
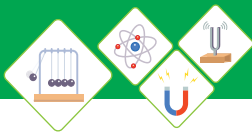



Fig 9.14
Real and Apparent expansion of liquids

Worked Example 3

A copper rod 15m long is heated, so that its temperature changes from 30°C to 85°C. Find the change in the length of the rod. The coefficient of linear expansion of copper is $17 \times 10^{-6}\,{}^{\circ}C^{-1}$.

Step 1: Write down known quantities and quantities to be found.

$$L = 15m$$
$$T = 30^{\circ}C$$
$$T' = 85^{\circ}C$$
$$\Delta T = T' - T = 85^{\circ}C - 30^{\circ}C = 55^{\circ}C$$
$$\alpha = 17 \times 10^{-6}\,{}^{\circ}C^{-1}$$
$$\Delta L = ?$$

Step 2: Write down formula and rearrange if necessary

$$\Delta L = \alpha L \Delta T$$

Step 3: Put values in formula and calculate

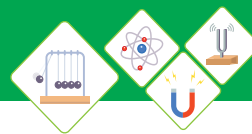
$$\Delta L = 17 \times 10^{-6}\,{}^{\circ}C^{-1} \times 15m \times 55\,{}^{\circ}C$$
$$\Delta L = 0.014m$$

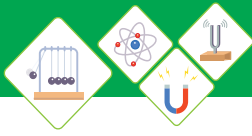
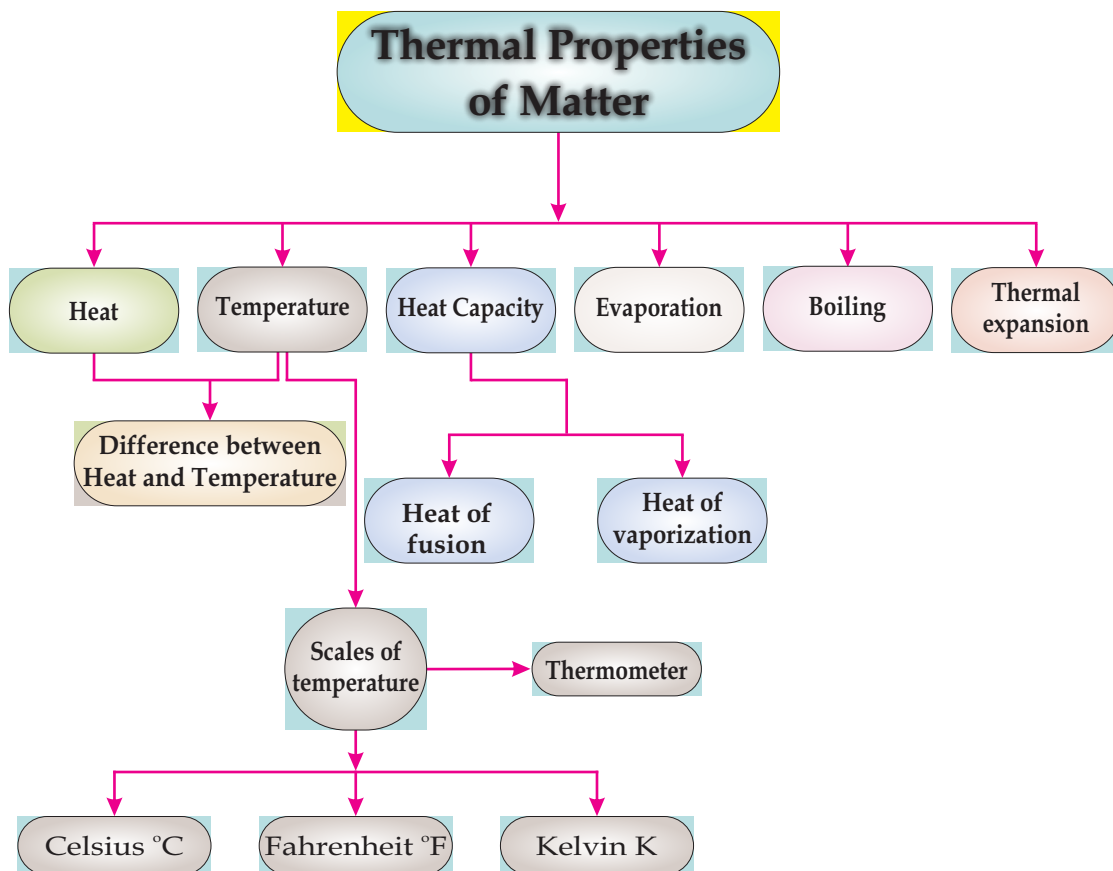
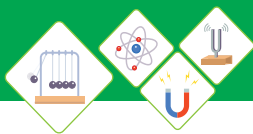
Hence, the change in length of the copper rod is 0.014m.

Self Assessment Questions:

Q12: What is the reason for expansion of solids on heating?

Q13: Explain two types of thermal expansion.

Q14: What is the relation between α and β?

SUMMARY

- Heat is the form of energy and its unit is Joule.
- Degree of hotness or coldness of a body is called as temperature.
- Temperature that determines the direction of transfer of thermal energy is called temperature..
- Three different scales, Celsius , Fahrenheit and are used for quantitative measurement of temperature.
- Temperature on Celsius scale is converted into Kelvin using $K = {}^{\circ}C + 273$.
- Temperature on Celsius scale is converted to Fahrenheit using: $F = 1.8{}^{\circ}C + 32$.
- Thermal energy transfer required per unit mass to raise the temperature by $1^{0}C$ or 1K is called specific heat capacity.
- The product of mass and specific heat capacity is called thermal capacity or heat capacity of an object.
- Thermal energy transfer required to change the state of a substance from solid to liquid without changing its temperature is called latent heat of fusion..
- Thermal energy transfer required to change the state of a substance from liquid into gas without changing its temperature is called heat of vaporization.
- The process in which liquid changes into gas without any external energy supply is called evaporation.
- Real expansion of water is the sum of apparent expansion of water and volume expansion of flask.

- Temperature, humidity, surface area of liquid, pressure, boiling point and moving air are the factors which affect the evaporation process of a liquid.
- Increase in length or size of a substance on heating is called thermal expansion.
- Increase in the length of a solid, when heated is called linear thermal expansion.
- Increase in volume of a solid, when heated is called volume thermal expansion.
- Volume thermal expansion of a solid depends upon increase in temperature, its original volume and properties of material.
- Increase in volume of a solid after heating is calculated by using $\Delta V = \beta V_0 \Delta T$.

Thermal Properties of Matter

- Heat
- Temperature
- Heat Capacity
- Evaporation
- Boiling
- Thermal expansion

Heat, Temperature → Difference between Heat and Temperature

Heat Capacity → Heat of fusion; Heat of vaporization

Temperature → Scales of temperature → Thermometer

Scales of temperature → Celsius °C; Fahrenheit °F; Kelvin K

End of Unit Questions

Section (A) Multiple Choice Questions (MCQs)

1. Heat is the form of __________
   a) Pressure b) Weight
   c) Energy d) All
2. Heat capacity is the product of mass and __________
   a) Boiling point b) Freezing point
   c) Energy d) Specific heat of material
3. The amount of heat needed to convert a substance from liquid to gas is called __________
   a) Heat of Vaporization b) Specific heat
   c. latent heat of fusion d) All
4. Thermal energy transfer required per unit mass to increase the temperature by 1^0C or 1 K is called ____
   a) Latent heat of Vaporization
   b) Specific heat capacity
   c) Latent heat of fusion
   d) Thermal capacity
5. A fixed temperature at which a pure liquid boils is called__________.
   a) melting point b) freezing point
   c) boiling point d) Both (a) and (b).
6. The melting point of ice at normal atmospheric pressure is __________.
   a) 0^0C b) 0K
   c) 100^0C d) Both (a) and (b)

7. Thermal energy transfer required to change a solid into liquid without changing its temperature is called __________.
   a) Latent heat of Fusion
   b) latent heat of vaporization
   c) latent heat of boiling
   d) specific heat capacity
8. Thermal energy transfer required to change a liquid into gas without changing its temperature is called
   a) latent heat of freezing
   b) latent heat of vaporization
   c) latent heat of boiling
   d) latent heat of melting
9. Evaporation can occur at __________
   a) freezing point b) melting point
   c) boiling point d) all temperatures
10. Rate of evaporation of a liquid can be increased by__________.
   a) increasing humidity
   b) decreasing temperature
   c) increasing its boiling point
   d) decreasing atmospheric pressure
11. Linear thermal expansion of a solid depends upon________________.
   a) increase in temperature
   b) original length
   c) properties of material
   d) all of these

Section (B) Structured Questions

Heat and Temperature

1. a) Define Heat and write its SI unit.
   b) Why does heat flows from hot body to cold body?
   c) Convert 30° C into Kelvin and Fahrenheit Scale.
2. a) Explain three different scales of temperature along with their main uses.
   b) Differentiate between heat and temperature.
   c) Convert 212°F into Celsius and Kelvin.

Specific Heat Capacity

3. a) Explain specific heat capacity.
   b) How would you find the specific heat of a solid?
   c) How much heat is required to boil 3 kg water which is initially 10° C ?
4. a) Explain the effects of large specific heat of water with examples from our daily life.
   b) 2kg of copper requires 2050J of heat to raise its temperature through 10°C. Calculate the heat capacity of the sample.

Heat of fusion and Heat of vaporization

5. Define heat of fusion with the help of an experiment.
6. Differentiate between heat of fusion and heat of vaporization
7. Demonstrate heat of fusion and heat of vaporization by the help of heating ice graph.

Evaporation Process

8. Explain in detail, why evaporation causes cooling?
9. Differentiate between evaporation and boiling.
10. Write any four factors that influence the surface evaporation.
11. Write down the freezing and boiling points of following
    i) Acetic acid　　ii) Benzene
    iii) Chloroform　　iv) Water

Thermal Expansion

12. Why solids increases in size on heating ? Explain.
13. An iron block of volume $3m^3$ is heated, so that its temperature changes from 25°C to 100°C. If the coefficient of linear expansion of iron is 11×10^{-6} $°C^{-1}$. What will be the new volume of the iron block after heating ?
14. a) Draw the diagram, showing real and apparent expansion of liquid. Label the diagram properly.
    b) Why small gaps are left at the joints of sections of railway tracks? Explain the phenomenon involved in it.